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Recovery of Gold by Single-Stage Deep-Fluidized Bed, Ion Exchange and Carbon Technique

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for

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Summary

Carbon-In-Pulp (CIP) processes are now widely applied in the major gold producing countries for the recovery of gold from pregnant leach solution. The technique provides significant economic benefits over the Merill-Crowe process. The next generation of gold recovery methods is likely to include continuous fluidized bed type adsorption process and a more economic desorption process. Such a system using ion exchange resins to recover elements such as uranium is well developed in the mineral industry. However, these multi-stage systems have complicated internals and control systems to regulate resin movements. In comparison single-stage deep fluidized systems have the attraction of relatively simple engineering and have been proposed for the recovery of metals from solution.

Prior to the development of such an extraction system it has been found necessary to conduct bench scale evaluations to determine the adsorption and elution characteristics of both ion exchange resins and activated carbon.

The present report summarizes the development work conducted for the project as described in Proposal No. P.4780-G issued to DSS under Contract No. ISQ85-00064. The objective of the program was to evaluate, on the bench scale, the adsorption, elution and electroelution efficiencies of ion exchange resins and activated carbons as applied to gold solutions.

The following elements were involved in the objectives:

- computer assisted literature review of all available related data
- stir tank adsorption tests on activated carbon and ion-exchange resins
- column adsorption of ion exchange resins
- stir tank elution of ion exchange resins
- pressurized caustic cyanide elution (Zadra) of activated carbon
- electro elution of activated carbon

1. Introduction

On January 8, 1985, the Ontario Research Foundation submitted a Proposal (No. P.4780-G) describing the bench scale development work for a project to investigate the recovery of gold by single-stage deep fluidized bed, ion exchange and carbon technique.

Phase I of the project was accepted on May 28, 1985 by DSS and a contract (No. ISQ85-00064) was awarded under DSS File No. 07SQ.23440-5-9026.

The scope of the program was to include:

- a computer assisted literature search and evaluation
- bench scale adsorption studies on activated carbons and ion exchange resins
- bench scale elution studies on activated carbons and ion exchange resins

The objective of the program was to evaluate activated carbons and ion exchange resins to facilitate the choice of a material and method of contact for the development of a pilot scale system incorporating the single stage deep fluidized bed technique for gold recovery from aqueous cyanide solutions.

In the present report the above testwork and results are described with recommendations for further work. A detailed critique based on the literature reviewed is also included.

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2. Literature Search

2.1 General

A computer assisted literature review has been conducted to obtain current information on the use of activated carbon and ion exchange resins for gold recovery. In obtaining the material, concentration was focussed on the carbon-in-pulp and resin-in-pulp processes, and recent developments in these areas.

The key words used for the computer search were: gold, carbon, resin(s), ion exchange and CIP. Related articles were collected and secondary references were consulted.

The following is a detailed critique based on the literature reviewed. References used appear in the appendix.

2.2 Introduction

The use of activated carbon for the extraction of gold from cyanided pulps has become extremely popular throughout the world. In the years since the advent of carbon-in-pulp (CIP) technology at Homestake Mine in 1973, considerable developments have been made which have led to a more efficient process. Some of these developments will be discussed.

Of recent interest in the western world has been the use of the resin-in-pulp (RIP) process as an alternative to CIP. Although RIP appears to be the favoured method of gold extraction in the Soviet Union it has had only limited applications in the rest of the world. Recent developments in RIP technology and a comparison of this method with CIP processes are reviewed.

2.3 CIP

2.3.1 CIP vs Merril Crowe

The CIP technique was originally developed in order to by-pass the expensive counter-current decantation (CCD) and filtration steps involved in the traditional Merril Crowe processing of gold ores. Many publications have since indicated the advantages of CIP over the Merril Crowe procedure in terms of both operating and capital costs, particularly at low head grades. Activated carbon has been found to be particularly advantageous in treating clarified or semi-clarified solutions such as are encountered in heap leach operations or in waste streams. Table 4 (from reference 1) summarizes the cost comparison of CIP and Merril Crowe techniques.

The cost advantages of CIP over Merril Crowe are obvious. However, these vary with the type of ore treated. Hard-to-filter ores, such as clays, demonstrate marked advantages for CIP. For filterable ores the CIP advantages decrease with increasing ore grade, with the break-even point estimated at a head grade of about 15 g/t (DeMent and King [4]).

Since most ores fall well below the 15 g/t limit this indicates that CIP is the more economical process. However, certain conditions may lead to retardation of CIP efficiency, especially if carbon fouling is indicated, and other processing methods may be required.

The choice of recovery technique is generally site specific, and the advantages and disadvantages of both CIP and Merril Crowe processes should be considered before a decision is made. A comparison of the two methods in terms of performance is given in Table 5.

2.3.2 CIP vs CIL

The carbon-in-leach (CIL) process is a recent trend in carbon adsorption technology. In this modification of the CIP technique, leaching and adsorption are carried out simultaneously. Schematics of typical CIP and CIL circuits are shown in Figures 1 and 2 respectively. The CIL process offers the advantage of lower capital costs, since a separate adsorption section is unnecessary. Disadvantages in CIL result from decreased adsorption efficiency since pulp conditions must be maintained for favourable leaching performance rather than for carbon adsorption (6). There is little information available comparing CIL to CIP for identical ores, and so actual performance results are inconclusive as to the cost advantages in either process.

Work conducted by Newrick et al (7) has indicated a savings in both capital and operating costs with CIL for theoretical ores analyzed by the Mintek (8) computer simultation program of CIL and CIP circuits. Although these results show advantages for the CIL process they are far from conclusive. It is envisioned that future comparisons of the two methods, based on actual plant data, will provide more concrete results.

The CIL approach has found particular application in the milling of carbonaceous gold ores, as it minimizes the adsorption capacity of the carbon components in the ore. This process is currently being employed at Mercur and Jerritt Canyon (58).

2.3.3 Developments in CIP Technology

The CIP circuit may be divided into five basic unit operations:

- milling and cyanidation
- adsorption of gold onto activated carbon
- elution of gold from loaded carbon
- recovery of gold from eluates
- reactivation of carbon

Recent developments in CIP technology will be discussed in terms of their applications within the flowsheet.

2.3.3.1 Milling and Cyanidation

For the most part, milling and cyanidation are standard in both CIP and Merril Crowe processes. However, recent findings have shown certain advantages in grinding ores in a cyanide solution prior to carbon recovery [9,10]. In this method, ground pulp is thickened and the overflow solution is fed to carbon columns while the underflow goes to leaching and CIP circuits. This procedure has the benefits of allowing increased throughput without decreasing carbon loadings. However, it is also sensitive to the ore type and thus can only be used under certain conditions; eg. ores with rapid leaching kinetics.

2.3.3.2 Adsorption

The adsorption stage is probably the most critical step in the CIP process. The extraction efficiency determines the soluble gold loss, the amount of gold "locked-up" in the plant and the carbon inventory. Efforts to optimize adsorption have led to developments in equipment design and in the understanding of the mechanisms of gold extraction by carbon.

Theory

The basic mechanism of gold extraction from cyanide solutions by activated carbon is not entirely understood. Many theories have been developed to explain the process, but much confusion and disagreement still remains. The difficulty in determining the adsorption mechanism arises from the lack of a direct method to chemically analyze activated carbon.

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The theories which have been developed to explain carbon adsorption fall generally into three categories [11]:

- gold is present as $[Au(CN)_2]^-$ and is held on carbon by electrostatic forces.
- gold is held on carbon as a compound other than $[AU(CN)_2]^-$; eg. AuCN
- gold is adsorbed by carbon in its metallic form.

Studies have indicated that the method of activation effects the adsorption capacity of carbon. Carbons prepared at high oxidation temperatures (> 750°C) have been found most suitable for gold adsorption [12]. This observation indicates the presence of certain surface species formed on the carbon which react with aurocyanide ions.

The design of a CIP adsorption circuit requires estimates of carbon concentration, number of stages, residence times, gold loading, and pulp and carbon throughputs. In order to evaluate these design parameters a detailed knowledge of the adsorption kinetics is required. The U.S. Bureau of Mines have developed a McCabe-Thiele approach using laboratory batch tests to establish equilibrium isotherms for gold/carbon systems [13]. The major drawback in this method involves the reliability of equilibrium data, since it requires weeks or even months for gold cyanide/activated carbon systems to reach equilibrium. Such conditions are not encountered during the much smaller residence times in CIP adsorption circuits.

Researchers at Mintek in South Africa have developed a kinetic model for adsorption based on empirical rate relationships [14]. The model may be based on laboratory or pilot-scale data and could prove to be useful not only in plant design but also in process control.

Equipment

Recent developments in carbon adsorption equipment have been mainly in the areas of screening, pulp agitation and carbon transport.

Screening - Two types of screening operations are required in CIP circuits; one in which the pulp is prescreened to remove oversize material which would contaminate the carbon, and a second by which the carbon and pulp are separated during the countercurrent adsorption process.

Problems encountered in commercial prescreening processes include:

- short life for metal screens
- surges of woodchips and of pulp
- woodchips overflowing and by-passing screens
- woodchips being forced through screens by pulp pressure

The use of polyurethane screen materials has increased screen life, but at the cost of decreasing the open area. Recently, Mintek has developed the EPAC (equalized-pressure air cleaned) screen to minimize problems in the prescreening stage. The process is shown in Figure 3 [15]. It has been successfully tested in South African plants. Laxen [15] reports some of the advantages of this procedure as follows:

- the tank can absorb woodchip surges
- the volume of pulp to the screen is small
- the woodchip concentration on the screen is high and thus washing is efficient
- the oversize in the pulp is low

Future screening processes may operate at even finer sizes. A trend towards two-stage screening units is also a possibility.

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Interstage screening to separate the carbon from the pulp has generally been performed by airlifting the material to external vibrating screens. Such a method has high capital and maintenance costs.

The use of EPAC screens for carbon-pulp separation has allowed major improvements in the adsorption circuit. Static EPAC screens are built as part of the contactor vessel. They may be located at the periphery of the adsorption vessel or along the side of the overflow launders. Launder screens may be sloping or V-shaped. The interstage screening arrangements are illustrated in Figures 4 through 7. These static screen processes have shown increased capacities and decreased maintenance costs.

More recently, the use of high frequency, low amplitude vibrating wire screens has been investigated. Capacities of greater than three times those for EPAC screens have been reported (16), though are not confirmed.

Pulp Agitation - Pulp agitation systems in CIP adsorption processes must induce high flows to allow maximum carbon-pulp contact, but also must produce low shear forces which cause carbon attrition. In recent years the trend has been away from air agitation (generally Pachuca tanks) to more economical mechanical methods. South African testwork has indicated significant improvements in gold adsorption for mechanical agitation systems (15).

Advantages of mechanical agitators include:

- lower power input
- decreased carbon fouling due to the formation of $CaCO_3$ (a significant problem in air agitated systems)
- greater effective volume of the contactor vessel
- lower capital costs since flat bottomed vessels may be used instead of more expensive Pachucas

Recently, the draft tube circulator has been successfully employed in CIP operations, particularly in South Africa. The impeller at the top of the vessel draws pulp down through the tube to induce circulation. Low energy costs and carbon attrition rates have been reported with this system. In addition, the draft tube circulator is reported to have quick start up characteristics with minimal associated problems.

Carbon Transport - Carbon transport within the adsorption circuit is most commonly performed by air lifts. However, this method has a number of disadvantages including high air flow and inconsistent pulp delivery to each stage. Recessed impeller pumps have recently been found to overcome the problems associated with air lifts [9].

Water eductors are the most commonly used method for transporting concentrated carbon. Problems with this technique include high water consumption, blockage of pipes and carbon attrition. Other methods for carbon transport include pressurized transfer vessels, which can provide greater heads at decreased water consumption. It is, however, a complicated and expensive system. For this reason transfer vessels have found limited application, particularly in smaller CIP plants.

2.3.3.3 Elution

There are three basic elution procedures for the recovery of gold from loaded carbon. These are:

- Zadra procedure
- Anglo American (AARL) procedure
- Solvent procedures

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Both the Zadra and AARL procedures strip loaded carbon with hot alkaline cyanide solutions and are enhanced at slight overpressures. The AARL technique differs from the Zadra approach in that the carbon is presoaked in the cyanide solution and subsequently eluted with pure water. The Zadra elution is performed with the cyanide solution as the eluent.

The Zadra and the AARL methods are widely used. The AARL procedure is the favoured method in South African plants, while the Zadra approach is more common in North American operations. There are indications, however, that some of the new South African plants will be converting to high pressure Zadra elution, since it has the advantage of continuous operation in closed circuit with electrowinning (15).

Until the recent development of the pressurized Zadra procedure, this method has suffered from the disadvantage of long cycle time (about 72 hours compared to the 10 hours required for AARL elution). Other problems in the Zadra system include a substantial bleed of eluate (about 33%). This is necessary to minimize chloride accumulation.

Disadvantages in the AARL procedure include the batch basis of operation and the need for good quality water. In most Australian plants, for example, deionizing of ground water prior to AARL elution is necessary.

Solvent procedures make use of the desorption properties of alcohol, ketones and organic nitriles to effect carbon elution at low cycle time (less than 8 hours). Commercial solvent elution processes use a caustic cyanide and alcohol mixture as the eluent. Major disadvantages in this system have limited its acceptance in the industry. These include the high fire risk associated with alcohol, and high operating costs due to alcohol loss by evaporation.

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Recent developments in solvent procedures have been made at Micron Research Ltd. [17] and at Murdoch University [18]. The Micron process involves conditioning loaded carbon with an alkaline cyanide solution followed by distillation desorption with methanol in a fractionating column, using the carbon as packing. Micron quotes a number of advantages for this method including the production of high grade electrolyte, cleaner stripped carbon and low capital costs. The micron elution method is currently being used at the Mount Bonnie gold/silver project in Australia [53]. The Murdoch investigations have concentrated on the use of acetonitrile, which has proved to be the most effective solvent tested to date.

2.3.3.4 Gold Recovery from Eluates

Gold recovery from eluate solutions in CIP circuits is achieved almost entirely by electrowinning. Zinc cementation is practised in some operations which previously had a Merryl Crowe circuit and are thus equipped with filtration equipment. Gold recovery by $CuSO_4$ precipitation has also been suggested. These methods, however, are not competitive with electrowinning due to high costs and the production of low quality bullion.

Electrowinning cells in commercial operation or in development include: the Zadra cell, the Anglo American cell, the NIM graphite chip cell and the Mintek parallel plate cell.

This discussion will concentrate on the NIM and Mintek cells, as they are the most recent designs.

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Prior to the development of the NIM cell in South Africa all commercial CIP electrolytic operations used steel wool as the cathode material. It provided the high surface area required for gold deposition from the low concentration solutions produced in carbon elution. In the NIM cell gold is deposited onto graphite granules, which act as the cathode. When the granules are loaded the barren electrolyte is drained from the cell and a solution of KOH and KCN is added. The cell polarity is reversed and gold from the graphite is deposited onto stainless steel anode plates.

The gold can be peeled from the plates and melted directly to bars of 99% by weight precious metal content (1). Pilot-scale results using NIM cells indicate high (greater than 90%) gold recovery in a single pass. No data is available on full-scale performance.

The Mintek parallel plate cell is a rectangular cell with steel wool cathodes packed into polypropylene baskets which are arranged in series within the tank. Electrolyte is passed through the series of parallel anodes and gold is deposited. Mintek cells are currently being tested in a number of South African plants. High gold loadings, low floor space and high recoveries have been reported.

A unique modification of conventional electrowinning techniques is the electrodesorption of gold directly from activated carbon. In this process gold is simulatenously desorbed from the charcoal and deposited as metal on a steel wool cathode. The technique is similar to the electroelution of ion exchange resins (59) (60).

The gold electrodesorption process has been studied on the laboratory scale by Gilmore at CANMET in Ottawa (61). An adaptation of the circular Zadra cell was used for these tests.

Loaded carbon was introduced to a compartment at the bottom of the cell, separated by a circular stainless steel screen which acted as the anode. Boiling 1% NaOH + 0.1% NaCN electrolyte was added and an emf was applied.

Gold extraction was reported as 97% in 2 hours. The spent electrolyte could be recycled to the next batch electrolysis and the carbon could be reused in the adsorption stage after thermal reactivation and acid washing.

The process was determined to be cost competitive with standard two-stage elution/electrolysis methods. The main advanatae of this system is that a separate elution step can be eliminated.

Other innovations in electrolytic cell design include investigations into the development of high surface area cathodes, such as fluidized bed and carbon fiber models [19].

2.3.3.5 Carbon Reactivation

Carbon must be reactivated prior to reuse due to the adsorption of various substances which are not removed by elution. Gold loading capacities are usually less than 5% of new carbon after a cycle is completed. Carbon regeneration is a two stage process consisting of acid washing and thermal reactivation.

Acid washing removes adsorbed calcium carbonate from the carbon. This can be achieved using either hydrochloric or nitric acid. Acid washing may be carried out in any one of three positions in the circuit: before elution, after elution or after thermal reactivation. The choice of position is generally site specific since each has its advantages and disadvantages. Washing after thermal reactivation is discouraged, however, since the degree of reactivation is reduced by the presence of impurities on the carbon surface.

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Early CIP plants performed acid washing in the same vessel as elution. This required the use of specialized linings. The recent trend has been towards the use of separate acid washing tanks made of stainless steel.

Thermal reactivation of carbon requires heating to temperatures above 650°C. This has commonly been carried out in externally heated rotary kilns. Problems with this method include low thermal efficiency (about 30%) as well as high capital and maintenance costs, particularly when furnaces are not operated continuously. More efficient furnaces are being designed and tested. These include internally [20] and externally [21] heated vertical tube furnaces, as well as the Mintek vibrating deck furnace (Figure 8). The tube furnaces are available commercially, but the Mintek furnace is still being developed.

Testwork is being conducted at Mintek in South Africa to determine the relationship between carbon activity and thermal reactivation parameters. Preliminary results indicate more efficient reactivation with increased temperatures and decreased water content of the carbon. These investigations are continuing. Future testwork may include studies to determine whether all the carbon must be thermally reactivated after each cycle or if only a portion of the total flow need undergo such treatment [15].

2.4 RIP

Resin-in-pulp technology is not new to the mining industry. It has been used for many years in the processing of uranium ores (Anaconda, for example). In Canada, research into RIP technology has been extensively carried out at CANMET. The application of RIP technology to gold and silver ores, however, has been limited. For the most part, the use of ion exchange resins has occurred predominantly in treating waste plating solutions

As a result of new developments in resin technology and screening techniques, a greater interest in RIP methods is evident. Russian reports indicate the widespread use of ion exchange for gold recovery in that country. In fact, it has been claimed that one of the largest gold mines in the Soviet Union is employing an RIP circuit [22]. Developments in the western world have only reached the pilot stage.

The RIP process has a number of advantages over CIP and may prove to be a viable alternative under certain conditions, such as in operations which experience a high degree of carbon fouling. The advantages of RIP include the following:

- superior kinetics and equilibrium loading of aurocyanide
- simple elution at ambient temperatures and pressures
- elimination of thermal reactivation
- elimination of acid washing
- elimination of "fouling" by organic species such as flotation reagents and lubricating oils, or by minerals such as clay and hematite

The RIP process also has some drawbacks, which must be weighed against the advantages when selecting a recovery method. The disadvantages include:

- decreased selectivity for gold
- screening difficulties due to the small size of resin particles
- lack of knowledge about the physical strength of resins in adsorption tanks
- low resin density results in the tendency to accumulate at pulp surfaces unless agitated efficiently

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As a result of recent interest in RIP technology for gold extraction, a pilot campaign has been initiated by Mintek in South Africa.

The use of both strong and weak-base anion exchange resins for gold recovery has been investigated over the years. Weak-base resins required pH modification to a value of 9 in order to function. The elution of weak-base resins, however, is simply performed by the addition of a fairly dilute caustic solution. Strong-base resins do not require pH adjustment, but elution is more difficult. Some methods which have been investigated to affect elution include the use of thiourea solutions as well as mixtures of chlorides or sulphides and organic solvents.

Mintek has developed a method for the elution of strong-base resins using zinc cyanide to displace aurocyanide. This process is advantageous since it may be carried out at high pH, and thus is compatible with existing gold processes. Zinc cyanide elution was the chosen method for the Mintek pilot scale testwork involving strong-base resins.

A major breakthrough for RIP processing was the introduction of the EPAC screening technique discussed earlier. The limitation of RIP in the past has stemmed from the lack of efficient screening methods for small particles. With the advent of these new screening devices, it is expected that pulp/resin separation will not be a problem in future RIP operations.

Mintek pilot scale research on RIP gold extraction involved tests with both strong and weak-base resins. A schematic representation of the circuit is shown in Figure 9. Tests with the resins and carbon were carried out over a six month period to generate data which could be compared.

Results from the investigation indicate similar performances in the RIP and CIP circuits, with stage efficiencies of between 70 and 75% for both the resins and carbon [14]. The non-selectivity of the resins for gold was balanced by the higher loading capacities.

Another observation recorded in the Mintek testwork showed that various base metals could be allowed to build up in the eluate without effecting gold recovery when using ion exchange resins. This indicates the possibility for RIP to be used to recover other metals which are present in gold ores.

The Mintek studies concentrated on the chemical, rather than physical, performance of RIP processing. Larger scale pilot plant tests are currently being conducted at Mintek to determine resin screening performance and attrition characteristics.

Recent South African testwork indicates that RIP processes may have distinct advantages over CIP in specific cases, such as the treatment of calcines, ores with large amounts of base metals and pulps containing entrained organic matter [14]. The latter case is apparent when flotation precedes cyanidation. Resin performance is affected by flotation reagents much less than activated carbon.

RIP technology may also find particular advantages in small gold plants. The capital and operating costs involved in carbon regeneration often cannot be justified in small operations. The alternatives of burning the carbon or selling it to a refinery result in high materials costs. In RIP processes, however, elution and regeneration may be performed at much lower capital and operating costs.

The similarity between CIP and RIP processes suggests an easy transition from one method to the other in operating plants. Hence, CIP operations could convert to RIP processing with minimal capital expenditure.

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2.5 FUTURE APPLICATIONS OF RESINS AND CARBON FOR GOLD RECOVERY

Both resins and carbon are likely to play key roles in future gold recovery processes. Although less is known about the performance of resins on gold ores, the ion exchange process is well developed for other metals, particularly uranium. Some of the technology designed for the recovery of these other materials will inevitably be applied to gold ore processing. Carbon adsorption and resin adsorption will both benefit from the research base available to the mining industry.

Future gold recovery processes are likely to utilize innovative technologies borrowed from other metal industries. In particular, the use of continuous fluid bed type adsorption processes for treating liquors and slurries will be more prominant in the gold industry. These have become relatively well developed over the years and offer the advantages of lower resin inventory as well as the ability to treat unclarified solutions. However, the multi-stage systems in current use are complicated.

The recent development of the single-stage deep fluidized bed system has combined the advantages of fluid bed technology with a relatively simple design. This method so far has been tested with ion exchange resins only. However, it would require only slight modifications to adapt the technology for use with activated carbon. It is foreseeable that the fluidized bed approach will be at the forefront of the next generation of gold recovery processes. Whether it will be used with ion exchange resins or with activated carbon depends on the results of current testwork.

The use of electrodesorption techniques may also have a greater impact in gold extraction processes. The elimination of the often inefficient and complicated elution stage would be a definite advantage for gold producers. More testwork on this technique needs to be conducted, however, before application on the plant-scale can be considered viable. Pilot-scale investigations would be particularly desirable to generate data on continuous operation and the recycle of material.

Future applications of resins and carbon will rely strongly on present research. Continuation of Mintek testwork is currently being undertaken by a number of organizations, including the Ontario Research Foundation. A more detailed understanding of loading and desorption characteristics of resins and carbon will be provided by current testwork. In addition, new techniques, such as electro desorption, are currently being evaluated. This pool of information will allow for the design of more efficient carbon and resin extraction systems in the future.

3. Testwork and Results

3.1 Activated Carbon

It is believed that gold in cyanide leach solutions exists as the cyanide complex, $Au(CN)_2^-$, which is produced by the following reactions:

$$2\,Au + 4\,CN^- + 2H_2O + O_2 \rightleftharpoons 2\,Au(CN)_2^- + H_2O_2 + 2OH^-$$

$$2\,Au + 4\,CN^- + H_2O_2 \rightleftharpoons 2\,Au(CN)_2^- + 2OH^-$$

The adsorption of gold from such leach solutions by carbon is claimed to take place either in a form chemically derived from aurocyanide (eg. AuCN), by the reduction of gold to the metallic state during adsorption, or typically as in an ion exchange mechanism. Extensive work by NIM and Anglo American Research Laboratories seem to support the former two theories.

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In all these cases, however, the physical properties of the chosen carbon and the chemistry of leach solutions have significant effects on the gold adsorption. To understand such effects several commercially available carbon samples were tested for their adsorption capacity and adsorption rate. These are:

Calgon PCB
Calgon GRC 22
Norit R2020
Norit R2515
Haycarb TRT 5
Haycarb XTY

3.1.1 Physical Characteristics

Prior to conducting adsorption tests, details on the physical characteristics of each carbon were obtained (Table 3). Hardness measurements were supplied by the manufacturers and refer to ASTM D.3082-79, standard test methods for ball pan hardness of activated carbon. The listed value is the percentage retained on the smaller mesh size after testing. Bulk density, pore volume, particle size, moisture content and pH values were experimentally obtained.

Attritioning tests were conducted on all carbons prior to their use in adsorption testing. Attritioning was conducted on 50 g lots of dry carbon with 100 ml of distilled water in a 500 ml bottle. The bottle was rotated end over end for 24 hours at 46 rpm. The values listed are the percent retained on the smaller mesh size after attritioning.

3.1.2 Loading Tests

3.1.2.1 Baseline Loading

Baseline carbon loading tests were conducted on 0.1, 0.25, 0.5 and 1.0 gram carbon samples in 500 ml of appr. 35 ppM gold solution. The solution contained 0.1% NaCN and was maintained at pH 10.5. Testing was conducted at room temperature in 2 L leach vessels with mechanical agitation at 400 rpm. The carbon loading and gold adsorption data after 24 hours contact is shown in Table 4 for all the carbons tested.

From the baseline loading tests, the adsorption kinetics for each of the activated carbons was calculated. A ranking of the carbons in terms of adsorption kinetics, capacities and physical characteristics is given in Table 5. A more detailed summary of these results (including the actual values obtained) is given in Table 6.

From the data summarized in Table 6, a statistical correlation of adsorption capacity to adsorption kinetics, bulk density, moisture content, pH and pore volume was calculated. Details of this interpretation of the data is given in Table 7. It was found that there was a linear relationship between adsorption capacity and pore volume as well as adsorption capacity and kinetics. There was no statistically supported relationship between adsorption capacity and any of the other variables.

3.1.2.2 Effect of Process Parameters

Loading conditions were varied according to the following outline:

	Baseline	Test Conditions
- temperature	22°C	6°C, 35°C
- pH	10.5	8.8 12.3
- cyanide concentration	0.1%	0.5%
- turbulence	400 rpm (all carbon suspended)	200 rpm (approx. 20% carbon in suspension)

These tests were carried out independently with only one factor being changed from base condition for each examination. Testing was conducted with 500 ml of a nominal 35ppM Au solution in a 2L vessel with 3 carbon additions; 0.1, 0.5, and 1.0g. The carbon loading after 4 hours contact for all carbons at each test condition is shown in Table 8.

3.1.3 Elution Tests

Two methods of carbon elution were examined in the test program; hot caustic cyanide column elution (Zadra technique) and electroelution.

These methods were employed to elute three carbons; Norit R2515, Calgon GRC 22 and Calgon PCB, which had been loaded to approximately 15 kg/t. These three carbons were selected from the six tested previously on the basis of their superior loading characteristcs. Norit R2515 was particularly chosen to compare the performance of a pelletized carbon.

3.1.3.1 Zadra Elution

Zadra type column elution tests were carried out on the 3 activated carbons to study the effects of changes in of elution temperature, cyanide concentration and caustic concentration on gold recovery. Elution was carried out in a 1/2" stainless steel column with a downflow of hot caustic cyanide solution. Five grams of each loaded carbon were eluted for 3 hours with a solution flowrate of 120 mls/hour, equivalent to approximately 10 bed volumes/hour.

Testing was carried out with one condition of temperature, caustic concentration and cyanide concentration being varied from baseline for each test. A summary of the operating conditions tested is given in Table 9.

Gold desorption characteristics under each of the conditions studied is given in Table 10 for all three carbons tested. Higher cyanide, higher caustic and higher temperatures proved to be most effective in terms of desorption capacity. Higher caustic and cyanide concentrations also resulted in higher rates of desorption.

3.1.3.2 Electrodesorption

As an alternative to the Zadra-type elution process described above, electrodesorption of the loaded carbon was tested. Electrodesorption is a method of carbon elution involving the simultaneous stripping of gold from loaded carbon to a solution electrolyte, and its plating onto a steel wool cathode by an applied electromotive force.

The three selected carbons were eluted in the apparatus shown in Figure 10. Five grams of loaded carbon were placed in the cell, 1 litre of electrolyte was added and the system brought up to temperature. An EMF of 2.5V was then applied for two hours.

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Test variables included temperature (80, 90, 100°C), caustic concentration (0.5, 1.0, 5.0% NaOH), and cyanide content (.05, 0.1, 1.0% NaCN). These conditions and the results of testing are summarized in Table 11.

3.2 Ion Exchange Resins

The application of anion exchange resins for recovering gold from cyanide solutions has been an accepted technology in the Soviet Union and has been practiced there using resin-in-pulp circuits.

The aurocyanide complex, $Au(CN)_2^-$, can be recovered from aqueous leach solutions by ion exchange methods, during which the following reactions may prevail:

$$R_3NX^- + Au(CN_2)^- \quad \underset{S}{} \qquad R_3N^+ Au(CN)2^- + X^- \quad \underset{S}{} \quad \text{(strong base resin)}$$

$$R_2NH{+}X^- + Au(CN)_2^- \quad \underset{S}{} \qquad R_2NH + Au(CN)_2^{-} + X^- \quad \underset{S}{} \quad \text{(weak base resin)}$$

S = resin phase

An evaluation of the above equilbria indicates the $Au(CN)_2^-$ complex can be adsorbed by strong base resins at a wider range of pH compared to weak base resins. This can be expected since protonation of the weak base resin at lower pH values influences the loading.

To determine the adsorption characteristics of ion exchange resins and to compare their performance to that of activated carbons, six commercially available resins were selected for the study. A summary of the resins and brief descriptions of each are listed in Table 12.

3.2.1 Resin Loading

3.2.1.1 Stir Tank Tests

Stir tank loading tests were conducted on pre-sulphated, washed resins. The resins were sulphated at 100 ml wet settled resin (wsr) per 2 L of 200 gpl H_2SO_4 solution. They were then washed to pH 4.5 - 5.0 with distilled water.

Resin loading was conducted on 2 ml samples of wet settled resin (wsr) in 200 ml of gold solution. Testing was performed in 400 ml beakers with a magnetic bar stirrer at 400 rpm for 2 minutes duration (sufficient time for equilibrium to be reached).

Test conditions such as NaCN content, gold content, temperature, pH and added metal ion concentrations were varied independently to provide data regarding their effects on resin loading. Tests with added metal ions (Cu, Fe and Pb) were specifically conducted due to the high loading capacity of resins for these contaminant cationic species. Details of the various test conditions studied and results of these investigations are given in Table 13.

3.2.1.2 Column Tests

Column loading tests were conducted on all seven of the resins studied in order to determine breakthrough curves and the loading capacities. The column tests were conducted at a flowrate of 40 BV/hr. using a feed solution of approximately 33 ppM Au and 1 gpl NaCN at ambient conditions.

Breakthrough curves for weak and strong base resins are shown in Figures 11 and 12, respectively. Gold loadings as a function of time for weak and strong base resins are shown in Figures 13 and 14, respectively. The most noticeable observation obtained from these results is the much higher loading capacity of the strong base resins as compared to the weak base variety.

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3.2.2 Resin Elution

Based on the loading performance of the resins in the column tests the following resins were selected for elution testing:

Amberlite IRA 400
Dow 21K -16+20M & -20+40M
Duolite A7
Ionac A305

The resins were bulk loaded in columns under conditions identical to those used for the baseline column loading tests described in Section 3.2.1.2. The strong base resins were loaded to approximately 45 g Au/l wsr, while the weak base resins were loaded to about 2.5 g Au/l wsr.

Both stir tank and column elution tests were conducted on the five resins. The weak base resins were eluted with a dilute caustic solution, while the strong base resins were eluted with a caustic zinc cyanide solution.

3.2.2.1 Stir Tank Tests

Stir tank elution tests were conducted on the chosen resins under various conditions to determine the effects of changes in operating parameters on gold recovery. The tests were conducted in beakers using a magnetic bar stirrer at 400 rpm. The elution capacities were determined by solution assays. The effects of the following variables were studied in these tests:

- temperature
- caustic addition (weak base only)
- zinc addition (strong base only)
- cyanide addition

Details of these tests and the percent elution after 5 minutes contact are given in Tables 14 and 15.

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3.2.2.2 Column Tests

Column elution tests were conducted on all five resins to determine their maximum elution capacities. The conditions used for these tests are the same as those outlined for the baseline tests in Tables 14 and 15.

Based on the data obtained plots of % gold eluted vs. bed volumes of solution through have been made for both weak and strong base resins. These are shown in Figures 15 and 16, respectively.

4. Discussion

From the test program and results summarized in the previous sections a number of observations are evident. These are presented in the following sections under the respective categories.

4.1 Activated Carbons

4.1.1 Loading

In terms of adsorption capacity, pore volume and loading under varied conditions the following carbons ranked highest (see Table 5): Calgon PCB, Calgon GRC 22 and Norit R2515. Haycarb XTY also showed a high capacity for gold adsorption. Gold loadings of up to 70.7 kg/tonne (Calgon GRC 22) were achieved after 24 hours contact in stirred tanks.

The only physical parameter found to be directly correlated with gold loading capacity was pore volume. This observation would indicate that a "molecular-sieve" type mechanism is likely to be responsible for the adsorption of gold species on to activated carbon.

This theory suggests that aurocyanide molecules are preferentially collected in the carbon's pore spaces while molecules of larger or smaller diameter are excluded. While direct proof for this mechanism is not available from the results, the strong relationship between pore volume and gold loading suggests that such an adsorption model is possible. In any case, pore volume may be considered a good initial indicator of the adsorption capacity of an activated carbon brand.

In general, the baseline loading conditions resulted in higher gold adsorption capacities than the other conditions tested. It would seem that this operating condition was the optimum under the range of variables examined.

The tests conducted at lower temperatures (6°C) were superior to higher temperatures (35°C) in terms of loading, but inferior nevertheless to the baseline ambient temperature. Low temperature and high temperature loadings were on average 83% and 73% respectively of base line loadings. At the low temperatures gold adsorption is most likely hindered by a decrease in the reaction kinetics. At the higher temperatures the decrease in loading is probably due to partial elution of the adsorbed gold species.

The decrease in gold adsorption at solution pH values other than the baseline condition is evident from the results. The higher loading of gold under the baseline pH condition is probably due to the fact that this range is near to each of the carbons' natural values. Deviation from this point thus resulted in decreased gold adsorption.

High solution cyanide concentrations were found to interfere with gold loading. This may be due to the partial elution of adsorbed gold.

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One of the most noticeable effects on gold adsorption occurred by decreasing the solution turbulence. At low turbulence (only 30% of the carbon suspended) the gold loadings were 82% on average of those achieved for the baseline conditions. This would indicate "Liquid Film Diffusion" as the controlling mechanism. For loading from dilute solutions this seems feasible.

4.1.2 Elution

Both the Zadra elution and the electroelution techniques were found to quantitatively desorb gold from the loaded carbons. A direct comparison of the two methods in terms of gold recovery would only be academic at best, due to the inherent differences in the two overall systems. One similarity in the two methods, however, is that all of the carbons tested ranked identically in terms of elution capacity in both of the techniques studied.

Calgon GRC 22 showed the highest elution capacity of the three carbons tested. It should be noted that this brand also showed the highest loading characteristics, thus indicating a relationship between adsorption and elution capacities for a given carbon.

For both elution techniques, increasing the temperature resulted in increased gold recoveries due to faster reaction kinetics. It would seem that the temperature variations examined in this study were sufficient to increase the reaction rates considerably.

In general, increasing the NaCN and NaOH concentrations of the Zadra eluant resulted in incrased gold recoveries to solution. This result has been previously documented by gold producers and is due to the complexation of gold species on the activated carbon with cyanide solution. In addition, increasing the solution pH (ie. by increasing the NaOH concentration) results in an increase in the rate of this reaction.

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For the electrodesorption tests, on the other hand, increasing the solution content of NaCN and NaOH generally resulted in a decrease in gold recovery. This occurrence is most likely due to the intereference of these ionic species at the elctrolytic of these ionic species at the elctrolytic deposition site (ie. steel wool).

4.2 Ion Exchange Resins

4.2.1 Loading

The most obvious conclusion noted from the resin loading tests is the much higher adsorption capacity of the strong base resins compared to that of the weak base variety. For example, in the column tests the strong base resin IRA-400 was loaded to 158 g/l wsr, while the highest weak base resin loading was only about 3.7 g/l wsr (Ionac A305). This observation has been noted previously (reference 1 of Appendix) and is due to differences in the nature of aurocyandide loading on to strong and weak base resins.

Details of these loading reactions have been discussed previously in this report (section 3.2). It should however be noted that weak base resins in the free-base form are uncharged and thus require protonation in order for aurocyanide extraction to occur. Protonation is affected by lowering the pulp or solution pH to below the pKa of the tertiary amine functional group. Testwork by NIM in South Africa on a number of commercially available weak base ion exchange resins (reference 1) showed that the maximum absorption of anionic species from solution occurred at pH values between 7 and 9.

The above analysis of the reaction-pathways for gold absorption would explain the higher loading capacity of strong base resins at the baseline pH value (10.2).

It also explains the reason for the greater sensitivity of weak base resins to changes in the solution pH. While both varieties showed higher absorption capacities at lower pH values, the effect was more profound on the weak base resins, with an average increase of 11.8% gold recovery in going from pH 12.3 to 8.7.

Loading tests conducted with added interfering ions also showed the higher affinity of strong base resins for dissolved anionic species. Although both resin types showed decreased gold loading with the addition of Cu, Fe and Pb ions to solution, the effect was most noticeable on the strong base resins. In addition, the recovery of copper during these tests was found to be higher for the strong base resins than for the weak base variety.

The effect of solution gold content was less quantifiable than that for the other ionic species noted above. The results at high and low solution gold concentrations were variable, thus indicating no correlation between the quantity of gold present and the loading capacity.

For both the stirred tank and column tests gold loading was found to be indirectly related to the size of the resin beads. Smaller resin sizes resulted in faster reaction kinetics and thus higher equilibrium loading capacities, as shown by tests conducted on Dowex 21K -20+40 mesh and -16+20 mesh resin beads. This would indicate that surface area plays a significant role in the rate of gold loading. In addition, the loading of other cationic species (ie. Cu) is increased with decreasing resin particle size, thus indicating a potential problem area in attempting to increase gold loading by using smaller resin beads.

For both the strong and weak base ion exchange resins the absorption reaction is enhanced at increased temperatures. This is in direct contrast with the results obtained for activated carbons, where increased temperatures resulted in decreased gold loading due to the partial redissolution of aurocyanide by the hot pregnant liquor. This occurrence obviously does not seem to take place with ion exchange resins, and is most likely due to differences in the two loading mechanisms.

As with the activated carbons, gold loading on to the ion exchange resins was hindered by the presence of excess cyanide in solution. The probable cause for this occurrence in ion exchange resins is likely to be due to a reversal in the absorption reaction caused by the presence of a high concentration of anions (ie. CN^-) in solution.

4.2.2 Elution

The main result of the elution studies in this program is the confirmation of previously documented evidence that weak base resins may be eluted more efficiently than the strong base variety. Specifically, the column elution tests showed that weak base resins, in general, elute much faster, with less eluant and more completely than strong base resins. In addition, weak base elution can be effectively accomplished using a simple eluant; dilute caustic solution. The result is that although weak base resins show poorer loading characteristics than strong base resins, elution is much simpler and more complete; a definite advantage in terms of process design considerations.

Improvement in strong base resin elution characteristics was not achieved by increasing the cyanide or zinc concentrations of the eluant (Table 14). This would indicate that the rate of this elution reaction can be only marginally increased by increasing the availability of either zinc or cyanide in solution.

This result is not totally unexpected since removal of the aurocyanide from strong base resins using zinc cyanide follows the reaction:

$$2|\text{-}^{+}NR_3Au(CN)_2^{-} + Zn(CN)_4^{2-} \rightleftharpoons (|\text{-}NR^{+}_3)_2\, Zn(CN)_4^{2-} + 2Au(CN)_2^{-}$$

Aurocyanide on the resin is displaced by zinc cyanide. Thus, the addition of zinc and cyanide to the eluant must be in such a ratio as to favour maximum formation of the $Zn(CN)_4^{2-}$ complex. An excess of either zinc or cyanide species alone would not result in increased gold recovery.

An increase in the performance of strong base resin elution was achieved by decreasing the eluant temperature to 5°C. The reason for this occurrence is uncertain, but may be due to a greater stability of the zinc cyanide complex at lower temperatures.

The weak base ion exchange resins were eluted using a dilute caustic solution and thus the reaction follows the equation:

$$|\text{-}^{+}NR_2HAu(CN)_2^{-} + OH^{-} \rightleftharpoons |\text{-}NR_2 + H_2O + Au(CN)_2^{-}$$

Considering this, it could be concluded that the rate and thoroughness of weak base resin elution is solely dependent upon the availability of OH^{-} ions in solution. The results from the test program would tend to substantiate this theory. Of the process variables tested (temperature, cyanide addition and caustic concentration), only caustic concentration had a significant effect on resin elution (Table 15).

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Similar to the results obtained during the resin loading tests, gold extraction during elution was increased with decreased particle size. Here again, surface area was found to have a significant effect on gold recovery, as seen from the Dowex 21K results (Figure 16).

5. Conclusions and Recommendations

Tests conducted to evaluate the effects of physical parameters of carbon on carbon adsorption indicate a strong correlation of pore volume to the adsorption capacities. Amongst the chosen carbon samples Calgon PCB, Calgon GRC 22, Norit 2515 and Haycarb XTY exhibited superior loading efficiencies. The results obtained on the effects of agitation indicate the likelihood of adsorption to take place by a liquid film diffusion mechanism.

Based upon the performance of the chosen carbons during adsorption and elution stages Calgon GRC 22 can be considered for testing by using single stage deep fluidized bed contactor. Even though initial loading results indicate higher loading with resin as against carbon, detailed comparison on the merits of RIP vs. CIP will be made when actual pilot plant data on loading, elution, attrition loss, fouling, impurity pick-up and hence the overall technical and economic viability are available.

Similarly the strong base resin IRA 400 using zinc cyanide as eluant and the weak base resin Duolite A-7 using caustic as eluant will be considered for pilot studies using single stage deep fluidized bed columns.

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Table 1

Comparitive Capital and Operating Cost Estimates for
CIP and Merril Crowe Cyanidation Procedures

Process		Cost Factor	
		Capital	Operating
Merril Crowe		1.00	1.00
CIP	1 (1)	0.68	0.77
	2 (2)	0.75	0.94
	3 (3)	0.75(4)	0.89(4)

NOTES: (1) Reference 2

(2) Reference 3

(3) Reference 4; DeMent and King; p.83-102

(4) at 3.5 g/t head grade, 93% gold dissolution

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Table 2

Comparitive Performances of
Merril Crowe and CIP Processes

	Advantages	Disadvantages
Merril Crowe	- efficient - simple design - inexpensive	- non-selective - high filtration costs - sensitive to pH and CN^- - gold loss due to incomplete filtration - sensitive to O_2 (requires de-aeration) - labour intensive
CIP	- efficient - simple design - inexpensive - higher recoveries - more selective - insensitive to impurities	- carbon fouling (esp. Ca and flotation reagents) - difficult to strip gold from carbon - discharged pulp can be high in cyanide - large water loss

(adapted from Muir, D.M.; reference 5, p.4)

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Figure 1: Typical CIP Circuit

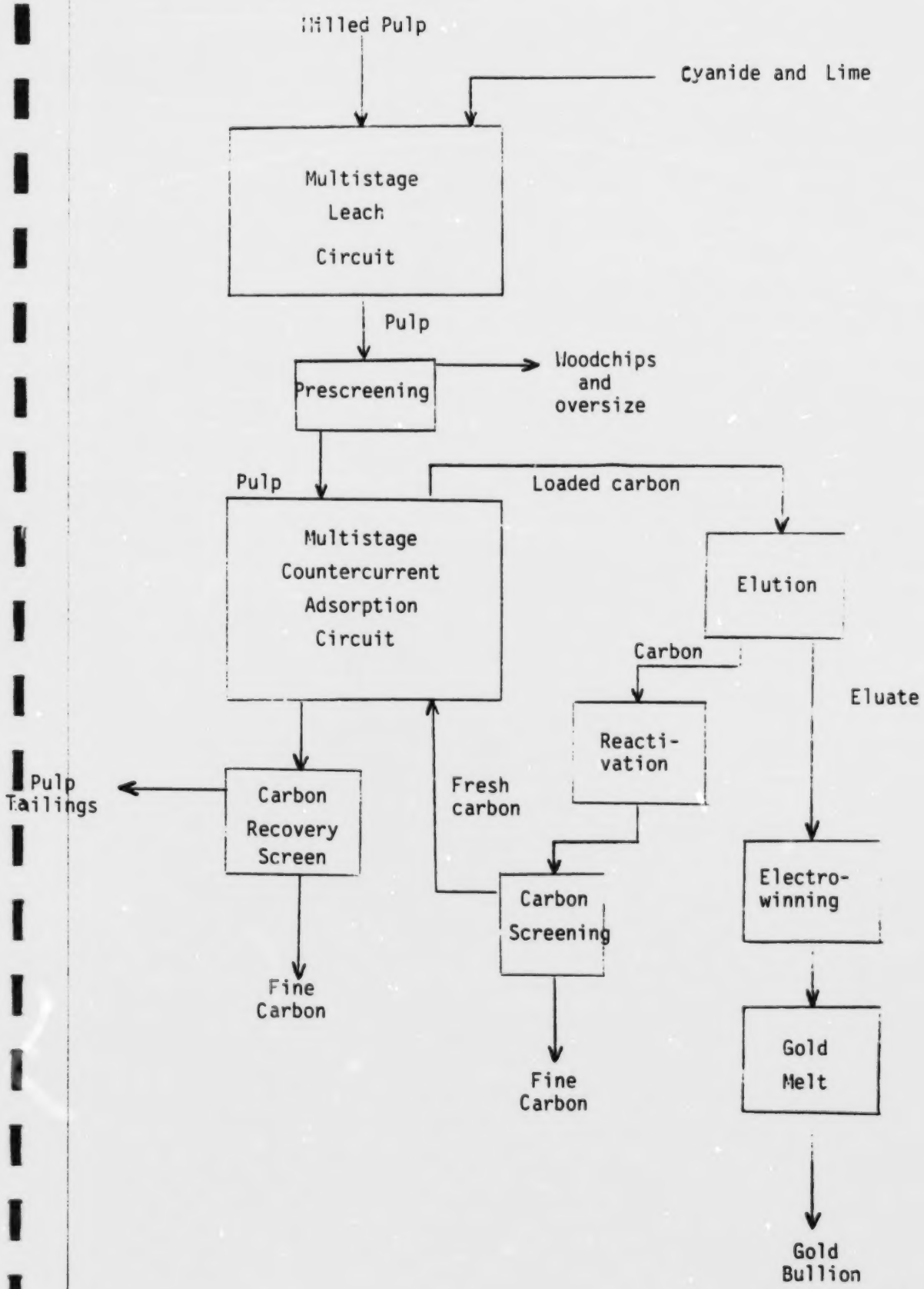

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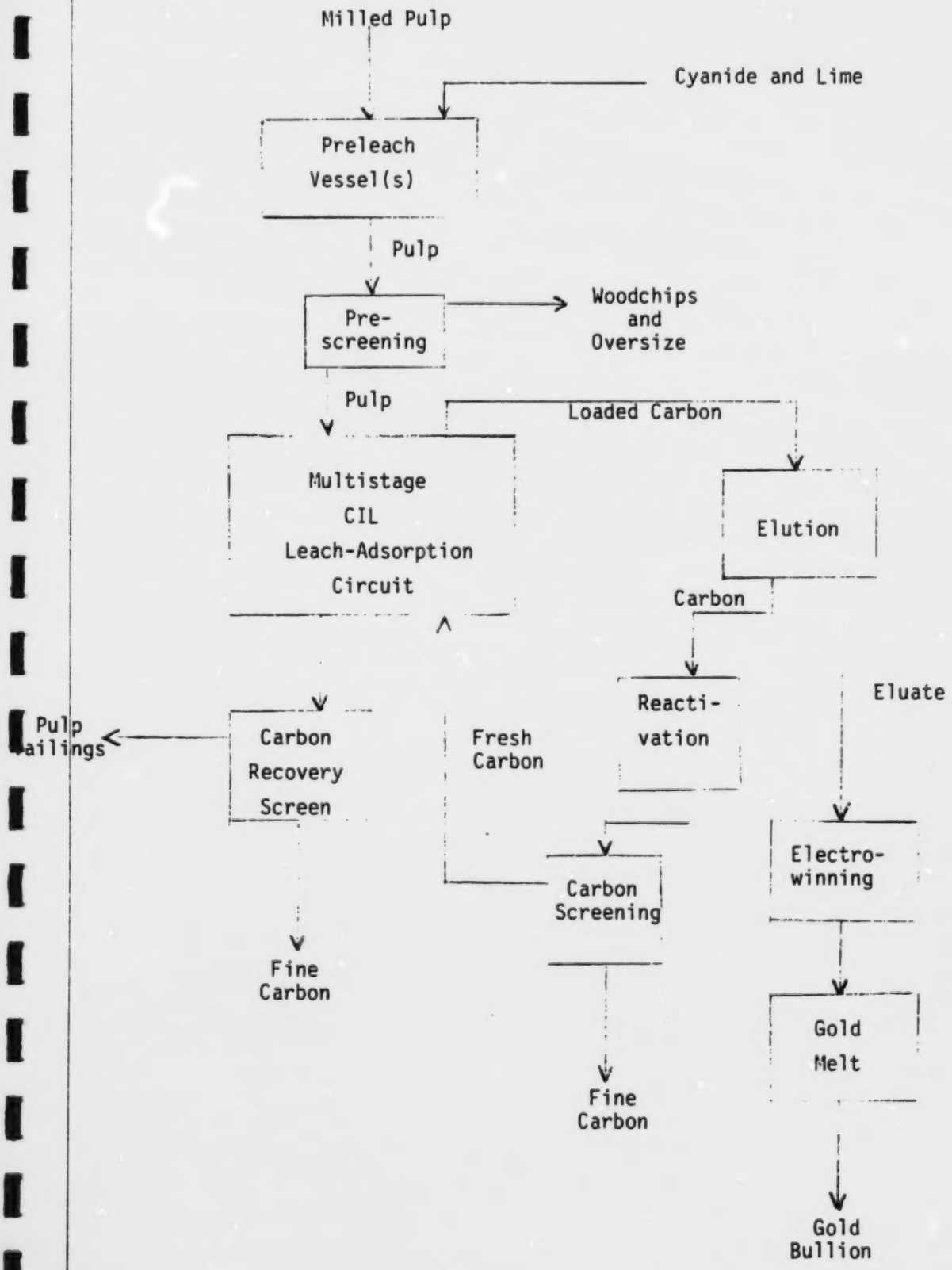
Figure 2: Typical CIL Circuit



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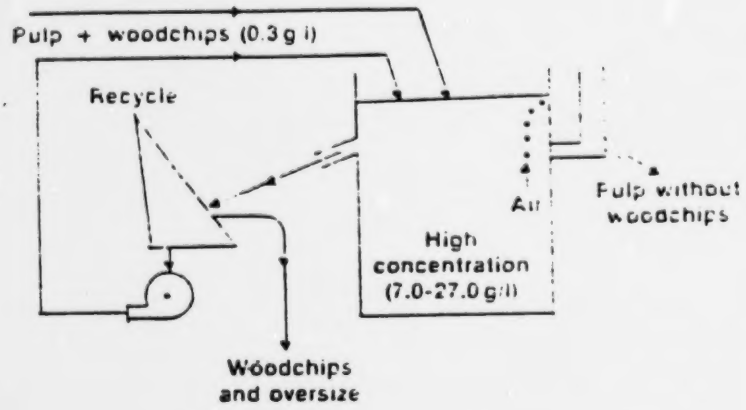
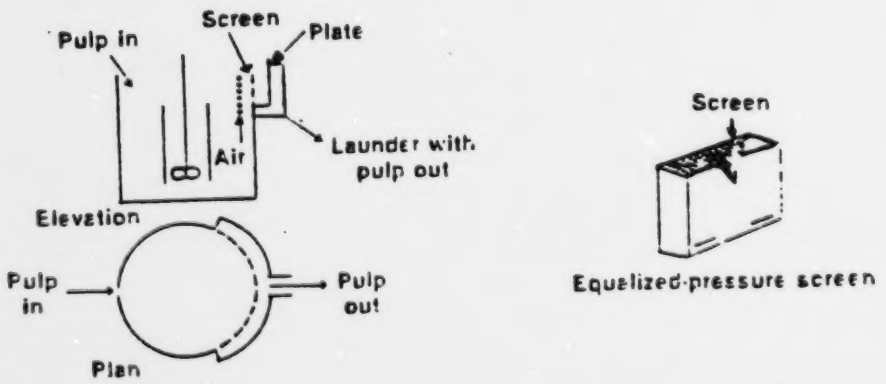


(15)

Figure 3: EPAC Prescreening System



(15)

Figure 4: Equalized Pressure Air-Cleaned Screens

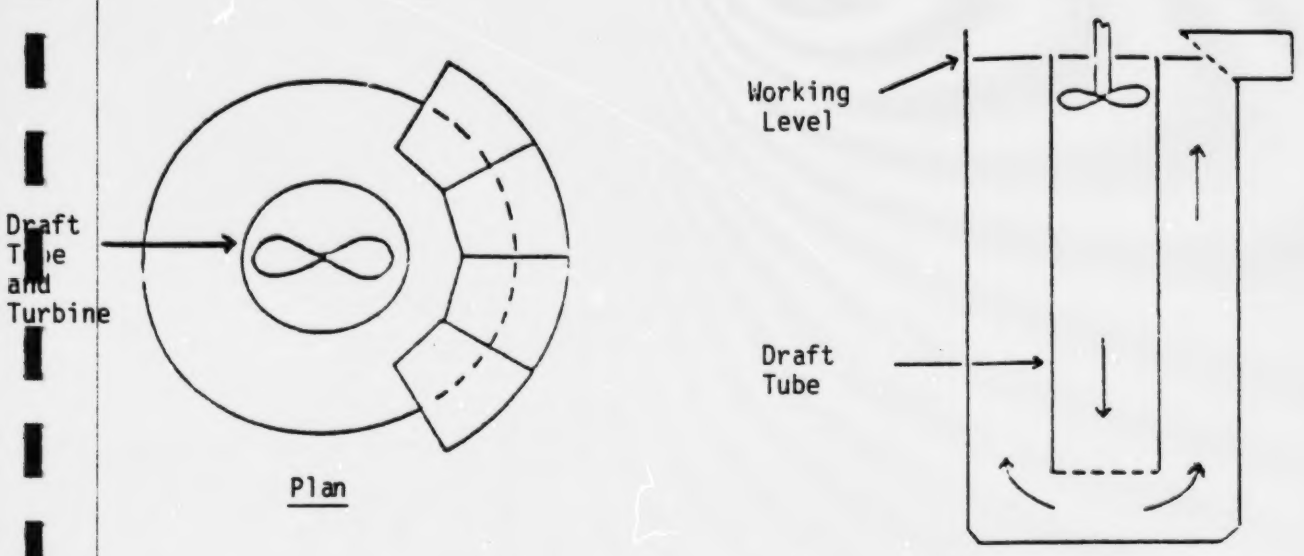


Figure 5: Peripheral EPAC Screen

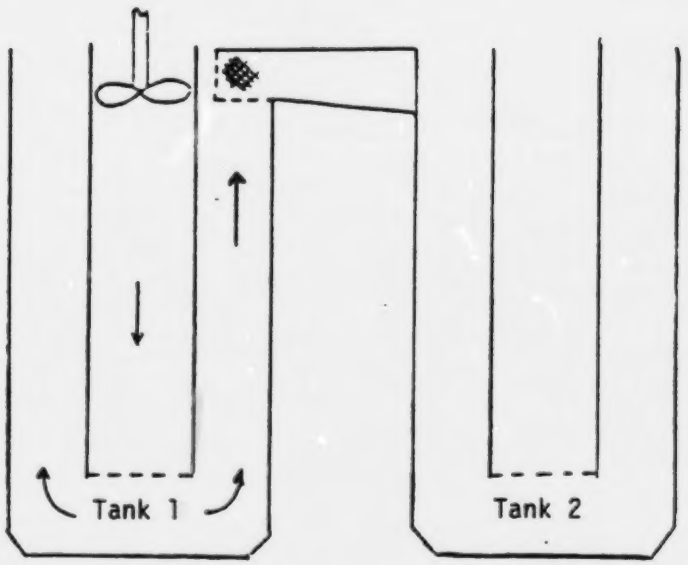


Figure 6: Sloping Launder Screen

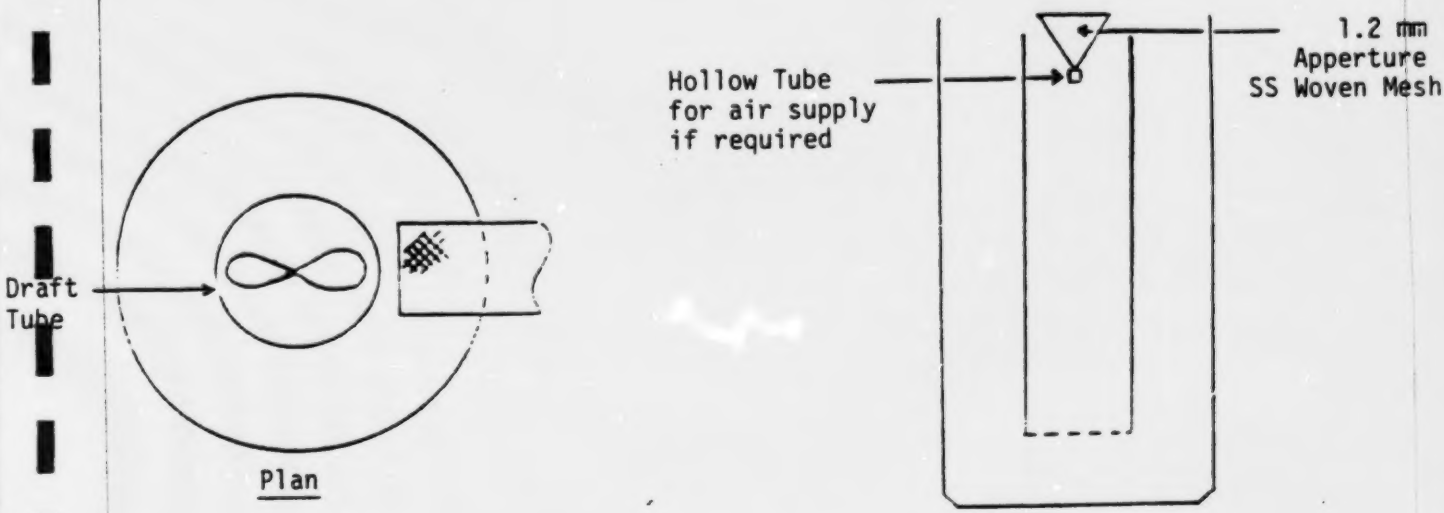
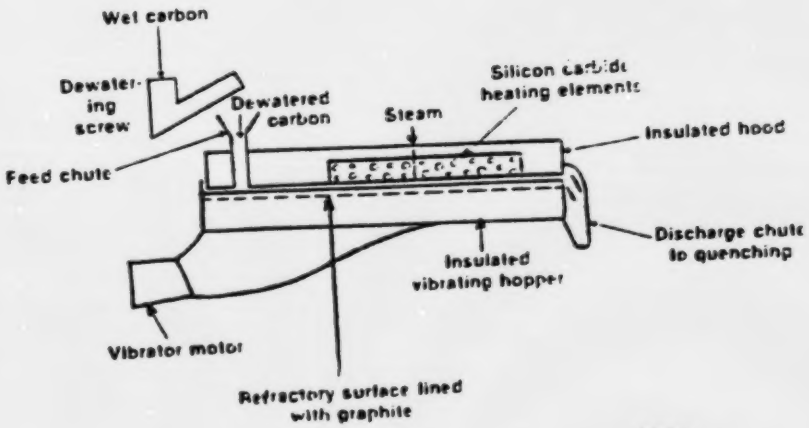


Figure 7: V-Shaped Launder Screen



(15)

Figure 8: Vibrating Deck Furnace

Figure 9: Mintek RIP Pilot Plant Flowsheet

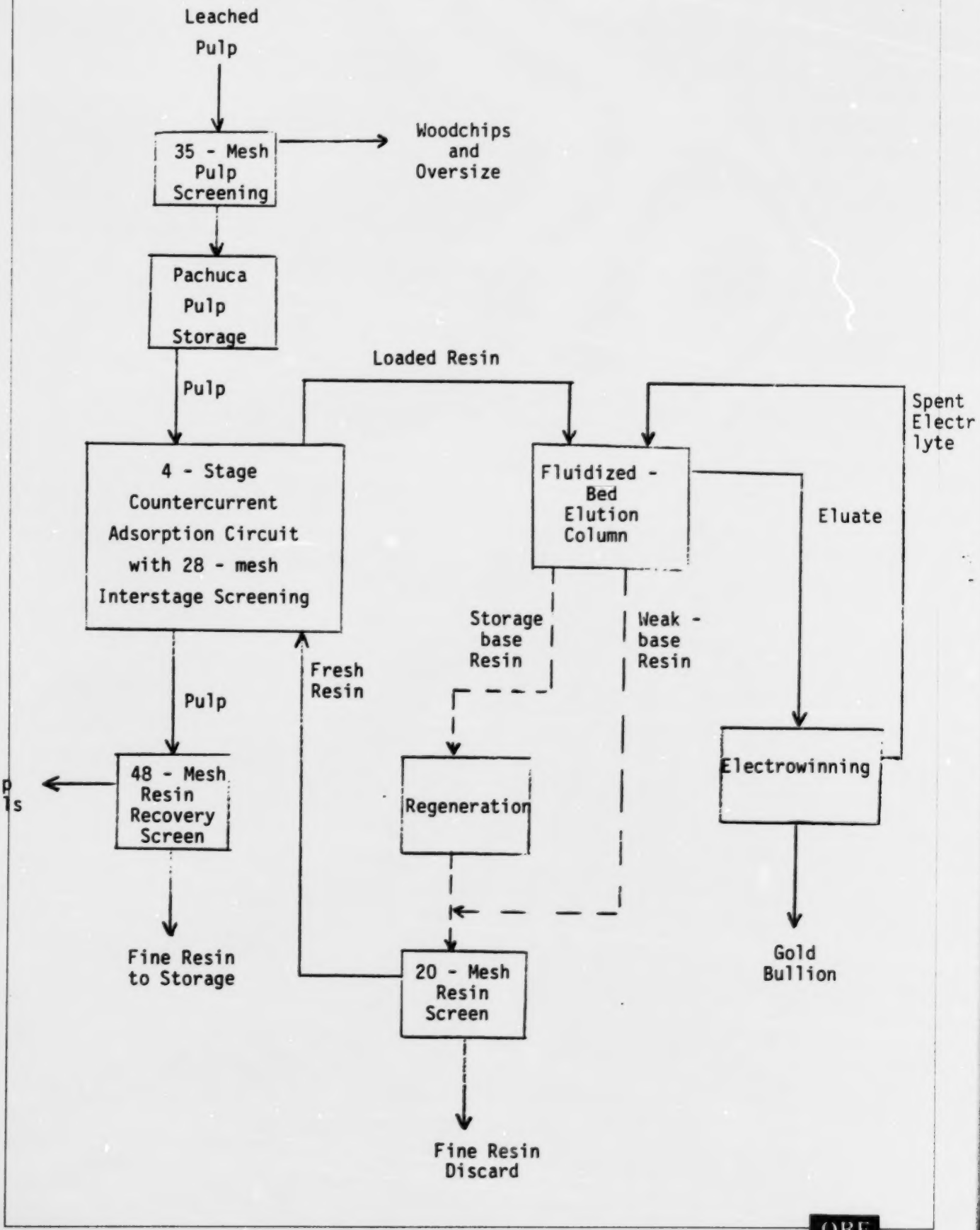


Table 3

Carbon Physical Characteristics

	Calgon GRC 22	Calgon PBC	Haycarb TRT 5	Haycarb XTY	Norit R2020	Norit R2515
Mesh size	6x16	6x16	8x16	8x16	2x4 mm	1.4x4 mm
Hardness % retained	98.0	92.0	99.0	98.8	99.0	100.0
Attritioning % retained	90.7	97.0	94.2	95.3	95.7	90.1
Bulk Density g/cc	0.47	0.44	0.56	0.49	0.52	0.50
Pore Volume cc/g	0.72	0.72	0.49	0.69	0.65	1.00
Moisture %	2.8	2.8	3.5	5.2	1.3	1.4
pH	9.7	9.8	9.9	9.9	10.6	10.6

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Table 4

Carbon Loading at Ambient Conditions
After 24 Hours

Carbon	Carbon/Solution Ratio (g C/500 mL Sol.)	Au Adsorption (%)	Au in Carbon (g/tonne)
Calgon PCB 6x16	0.1	36.9	70,479
"	0.25	63.5	48,514
"	0.5	86.8	33,158
"	1.0	98.3	18,775
Calgon GRC 22 6x16	0.1	37.0	70,670
"	0.25	70.6	53,938
"	0.5	86.1	32,890
"	1.0	98.9	18,890
Haycarb XTY 8x16	0.1	29.8	56,918
"	0.25	56.9	43,471
"	0.5	68.7	26,270
"	1.0	98.1	18,737
Haycarb TRT 5 8x16	0.1	11.4	18,980
"	0.25	27.3	18,468
"	0.5	54.9	18,282
"	1.0	90.9	17,362
Norit R2020 2mm	0.1	27.9	53,290
"	0.25	45.6	34,840
"	0.5	75.7	28,918
"	1.0	96.9	18,508
Norit R2515 1mm	0.1	13.0	21,650
"	0.25	54.1	36,032
"	0.5	83.5	27,806
"	1.0	99.8	19,062

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Table 5

DSS
Carbon Comparison

Carbon	Adsorption Capacity	Adsorption Kinetics	Attrition (ORF)	Bulk Density (Hi-Lo)	Moisture (Hi-Lo)	Pore Vol (Hi-Lo)	pH (Hi-Lo)
Calgon GRC22	2	3	5	5	3	2	4
Calgon PBC	3	2	1	6	3	2	3
Haycarb TRT5	6	6	4	1	2	5	2
Haycarb XTY	4	4	3	4	1	3	2
Norit R2020	5	5	2	2	5	4	1
Norit R2515	1	1	6	3	4	1	1

Table 6

DSS Carbon Ranking Under Ambient Conditions

1) Adsorption capacity after 24 hours - Ranking

1. Norit R2515 (19.0 kg/tonne)
2. Calgon GRC 22 (18.9 kg/tonne)
3. Calgon PBC (18.8 kg/tonne)
4. Haycarb XTY (18.7 kg/tonne)
5. Norit R2020 (18.5 kg/tonne)
6. Haycarb TRT 5 (17.4 kg/tonne)

2) Adsorption Kinetics - Ranking (m = slope of ln (xo/x) vs t)

1. Norit R2515 (m = 1.29)
2. Calgon PBC (m = 1.07)
3. Calgon GRC 22 (m = 0.96)
4. Haycarb XTY (m = 0.83)
5. Norit R2020 (m = 0.72)
6. Haycarb TRT 5 (m = 0.54)

3) Hardness Ranking - manufacture supplied (ASTM D.3802 - 79)

1. Norit R2515 (100% retained)
2. Norit R2020 (99% retained)

Tie 2. Haycarb TRT5 (99% retained)

3. Haycarb XTY (98.9% retained)
4. Calgon GRC 22 (98% retained)
5. Calgon PBC (92% retained)

4) Attritioning Ranking - ORF Test

1. Calgon PBC (97% retained)
2. Norit R2020 (95.7% retained)
3. Haycarb XTY (95.3% retained)
4. Haycarb TRT5 (94.2% retained)
5. Calgon GRC 22 (90.7% retained)
6. Norit R2515 (90.1% retained)

Table 6 (Cont'd.)

5) Bulk Density (Decreasing Order)

1.	Haycarb TRT 5	(0.56 g/cc)
2.	Norit R2020	(0.52 g/cc)
3.	Norit R2515	(0.50 g/cc)
4.	Haycarb XTY	(0.49 g/cc)
5.	Calgon GRC 22	(0.47 g/cc)
6.	Calgon PBC	(0.44 g/cc)

6) Pore Volume (Decreasing Order)

	1.	Norit 2515	(1.00 cc/g)
	2.	Calgon GRC 22	(0.72 cc/g)
Tie	2.	Calgon PBC	(0.72 cc/g)
	3.	Haycarb XTY	(0.69 cc/g)
	4.	Norit R 2020	(0.65 cc/g)
	5.	Haycarb TRT 5	(0.49 cc/g)

7) Moisture (Decreasing Order)

1.	Haycarb XTY	(5.2%)
2.	Haycarb TRT 5	(3.5%)
3.	Calgon GRC 22	(2.8%)
3.	Calgon PBC	(2.8%)
4.	Norit R2515	(1.4%)
5.	Norit R2020	(1.3%)

8) pH (Decreasing Order)

1.	Norit R2515	(10.6)
1.	Norit R2020	(10.6)
2.	Haycarb XTY	(9.9)
2.	Haycarb TRT 5	(9.9)
3.	Calgon PBC	(9.8)
4.	Calgon GRC 22	(9.7)

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Table 7

Carbon
Statistical Correlation of Data

	Dep. Var.	Indep. Var.	r	R^2	to	t.025,4	Linear Relationship
1)	Adsorp. Cap	Adsorp. Kinetics	0.837	0.700	3.056	2.776	Yes
2)	Adsorp. Cap	Bulk Density	-1.039	1.08	-	2.776	No
3)	Adsorp. Cap	Moisture	-1.506	2.268	-	2.776	No
4)	Adsorp. Cap	pH	0.484	0.234	1.106	2.776	No
5)	Adsorp. Cap	Pore Vol.	0.815	0.664	2.812	2.776	Yes

1) $S_{yy} = 1.876$ $S_{xx} = 0.351$ $S_{xy} = 0.679$
$r = 0.792$

2) $S_{yy} = 1.876$ $S_{xx} = .0085$ $S_{xy} = -0.135$
$r = 1.039$

3) $S_{yy} = 1.876$ $S_{xx} = 0.828$ $S_{xy} = -0.667$
$r = 1.506$

4) $S_{yy} = 1.876$ $Sxx = 0.828$ $S_{xy} = 0.603$
$r = 0.484$

5) $S_{yy} = 1.876$ $S_{xx} = 0.137$ $S_{xy} = 0.413$
$r = 0.815$

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Table 7 (Cont'd.)

r = correlation coefficient between x and y = $\dfrac{S_{xy}}{[S_{xx}S_{yy}]^{1/2}}$

R^2 = coefficient of determination

t_o = appropriate test statistic for hypothesis testing = $\dfrac{r\sqrt{n-2}}{\sqrt{1-r^2}}$

ie: H_o: $p = 0$]
- if $|t_o| > t_{\alpha/2,\, n-2}$
H_1: $p = 0$] then null hypothesis is rejected and correlation is considered linear

$t_{.025,4} = t_{\alpha/2,\, n-2}$ = students t distribution for 95% confidence interval, 6 degrees of freedom.

Table 8

Effect of Changes in Process Variables on Carbon Loading

Loading in kg/tonne C

A) 1.0 g carbon/500 ml NaCN solution

Test Conditions Examined	Calgon PCB	Norit R2020	Calgon GRC-22	Norit R2515	Haycarb TRT5	Haycarb XTY
Baseline Test	17.15	13.96	16.78	17.09	14.17	16.81
High Cyanide (.5% NaCN)	15.30	11.95	15.33	13.92	12.82	15.00
High Temperature (35°C)	13.27	11.47	12.84	13.06	7.49	13.52
Low Temperature (6°C)	14.41	14.22	14.44	13.14	10.31	14.46
Low pH (pH 8.7)	15.76	13.35	15.50	15.11	14.50	15.43
High pH (pH 12.3)	14.28	11.30	14.22	14.02	13.02	13.64
Low turbulence (200 rpm)	13.85	10.56	13.78	13.30	11.14	13.68

B) 0.5g carbon/500 ml NaCN Solution

Baseline Test	26.43	19.63	26.36	16.55	12.59	24.87
High Cyanide	24.05	13.25	24.00	20.54	15.84	23.04
High Temperature	17.70	13.64	18.62	19.31	14.12	18.35
Low Temperature	22.25	13.13	21.87	17.26	15.44	21.49
Low pH	23.76	16.60	23.51	19.73	18.20	22.04
High pH	22.85	13.15	22.46	17.86	17.95	21.22
Low turbulence	19.97	12.19	19.58	17.47	14.59	19.20

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Table 9

Test Conditions for Column Elution

Test Variable	Baseline Condition	Test Conditions
Temperature	100°C	88°C, 120°C
NaCN Content	.1%	0.05%, 0.5%
NaOH Content	1%	0.5%, 5%

Table 10

Column Elution (% Gold Eluted)

Carbon:	Norit 2515			Calgon PCB			Calgon GRC		
Time (hrs.):	1/2	1	3	1/2	1	3	1/2	1	3
Condition:									
low temp.	1.43	2.96	10.40	1.28	3.16	13.71	1.58	3.19	15.91
low NaCN	13.54	18.07	24.93	11.96	16.66	29.32	16.41	22.26	35.13
low NaOH	9.29	11.54	20.81	8.98	10.41	24.11	10.65	13.85	30.44
baseline	12.49	18.33	49.68	11.16	21.64	62.72	15.54	26.31	77.62
high temp	19.83	25.91	65.64	32.73	39.77	72.62	25.09	35.13	73.16
high NaCN	25.31	28.60	65.80	31.71	40.94	75.90	36.37	44.25	81.51
high NaOH	13.06	18.43	51.15	20.92	30.80	83.33	22.01	28.26	79.22

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FIGURE 10

Electrodesorption Cell

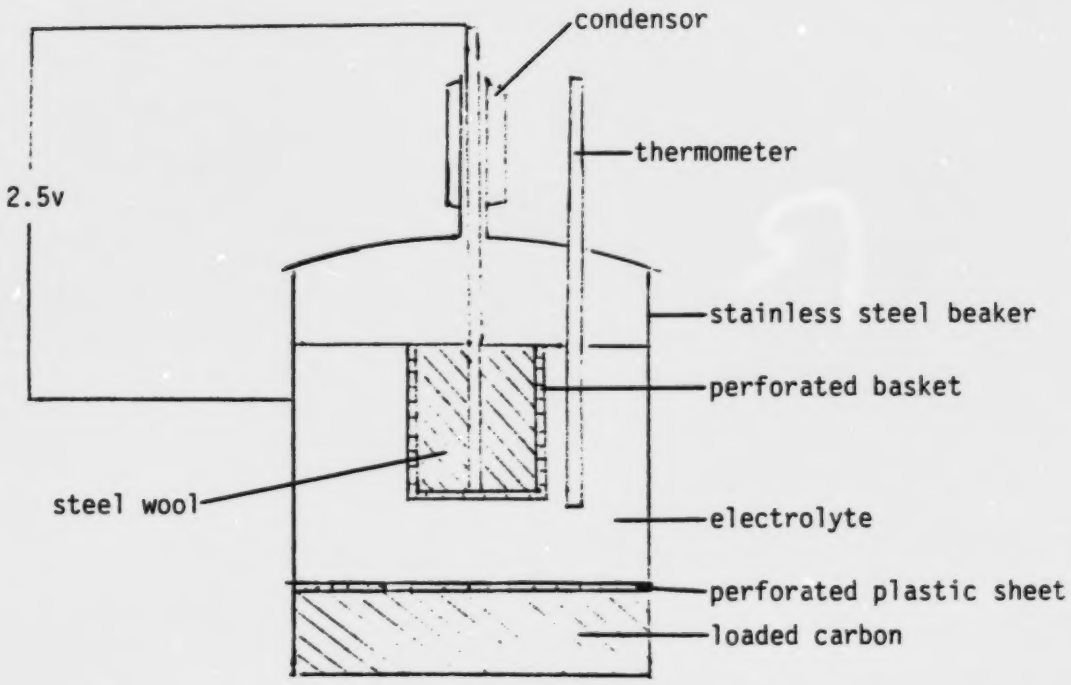

Table 11

Electrodesorption Results

	TEST CONDITIONS		GOLD DISTRIBUTION (% Au Available)		
	SOLUTION NaCN + NaOH%	TEMPERATURE °C	CARBON	SOLUTION	STEEL WOOL
CARBON	Low	80	54.8	45.2	0
	High	80	51.3	37.5	11.2
	Low	90	15.1	52.7	32.2
CALGON	High	90	30.8	52.9	16.3
GRC 22	Low	100	7.6	73.6	18.8
	High	100	29.7	34.8	35.5
	Baseline	100	13.9	17.1	69.0
	Low	80	60.5	20.8	18.7
	High	80	71.3	19.6	9.1
	Low	90	44.3	29.4	26.3
	High	90	62.3	25.7	12.0
CALGON	Low	100	16.2	13.5	70.3
PCB	High	100	39.7	31.8	28.5
	Baseline	100	19.1	10.5	70.4
	Low	80	74.7	13.4	11.8
	High	80	57.0	16.1	22.9
	Low	90	55.7	21.5	22.8
	High	90	71.8	24.2	4.0
NORIT	Low	100	40.5	20.1	39.4
2515	High	100	52.6	34.9	12.5
	Baseline	100	41.6	14.8	43.6

CONDITIONS

Voltage:	2.50V	Steel Wool:	8.0 grams
Amperage:	.25A	Time:	2.0 hours
Carbon:	5.00 grams	Volume:	1.0 litres solution

SOLUTION NaCN AND NaOH CONTENT	low	0.5% NaOH	0.5% NaCN
	baseline	1.0% NaOH	0.1% NaCN
	high	5.0% NaOH	1.0% NaCN

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Table 12

Summary of Ion Exchange Resins Tested

Resin	Type
Amberlite IRA 400 (16-50m)	gelular, strong base anion resin
Sybron Ionac SR3 (16-50m)	macroporous chelating
Sybron Ionac SR3 (10-40m)	granular, mixed intermediate
Dow XSF 4132	chelating anion resin
Dowex 21k (16-20m)	strong base anion resin
Dowex 21k (20-40m)	strong base anion resin
Duolite A7 (16-50m)	macroporous weak base anion resin

Table 13

Stir Tank Resin Loading (% Gold Recovered)

Resin	Test Condition					
	Low Cyanide	High Cyanide	Low pH	High pH	Low Temp	High Temp
Amberlite IRA 400 (16-50m)	40.1	37.4	41.2	39.1	27.7	52.9
Sybron Ionac SR3 (16-50m)	29.2	19.0	36.0	9.4	20.7	29.9
Sybron Ionac A305 (10-40m)	16.4	9.9	12.0	13.3	10.0	17.5
Dow XFS 4132	6.6	4.8	11.7	7.3	4.3	7.7
Dowex 21K (16-20m)	18.7	18.1	21.9	20.3	11.9	24.3
Dowex 21K (20-40m)	38.9	38.0	36.6	34.2	25.2	50.8
Duolite A7 (16-50m)	25.6	18.1	33.9	10.3	17.3	29.2

Resin Loading Test Conditions:

	pH	Cyanide Content (% NaCN)	Temperature (°C)	Solution Gold Content (ppM)
High	12.3	0.50	35	100
Baseline	10.2	0.10	22	33
Low	8.7	0.05	6	10

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Table 13 (Cont'd.)

Stir Tank Resin Loading (% Gold Recovered)

	Test Condition					
Resin	Low Gold Content	High Gold Content	Low Interfering Metal Addition		High Interfering Metal Addition	
Amberlite IRA 400	38.5	37.1	33.4	(17.5)*	20.2	(15.2)
Sybron Ionac SR3	29.8	29.4	20.3	(0)	20.2	(5.4)
Sybron Ionac A305	14.4	17.9	6.6	(7.1)	6.2	(4.9)
Dow XFS 4132	6.7	0	7.4	(1.3)	10.1	(10.3)
Dowex 21K (16-20m)	19.2	23.4	19.1	(14.9)	12.1	(9.2)
Dowex 21K (20-40m)	37.5	40.3	32.9	(27.9)	20.8	(12.0)
Duolite A7	29.8	25.0	21.4	(6.5)	18.8	(2.7)
Total Metal Addition:			0.2 gpl Cu 2.5 ppm Fe trace Pb		1.8 gpl Cu 68 ppm Fe 2 ppm Pb	

* numbers in brackets are % Cu recovered

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FIGURE 11

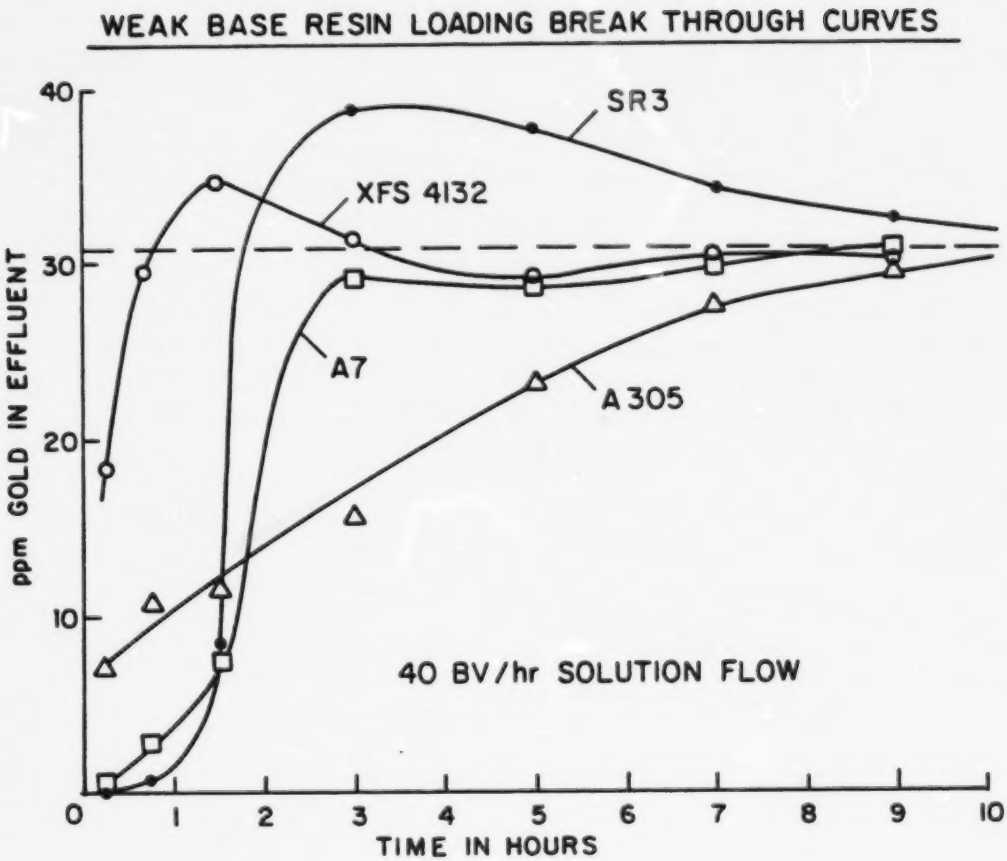
WEAK BASE RESIN LOADING BREAK THROUGH CURVES
SR3
XFS 4132
A7
A 305
40 BV/hr SOLUTION FLOW
ppm GOLD IN EFFLUENT
TIME IN HOURS
0
1
2
3
4
5
6
7
8
9
10
10
20
30
40

FIGURE 12

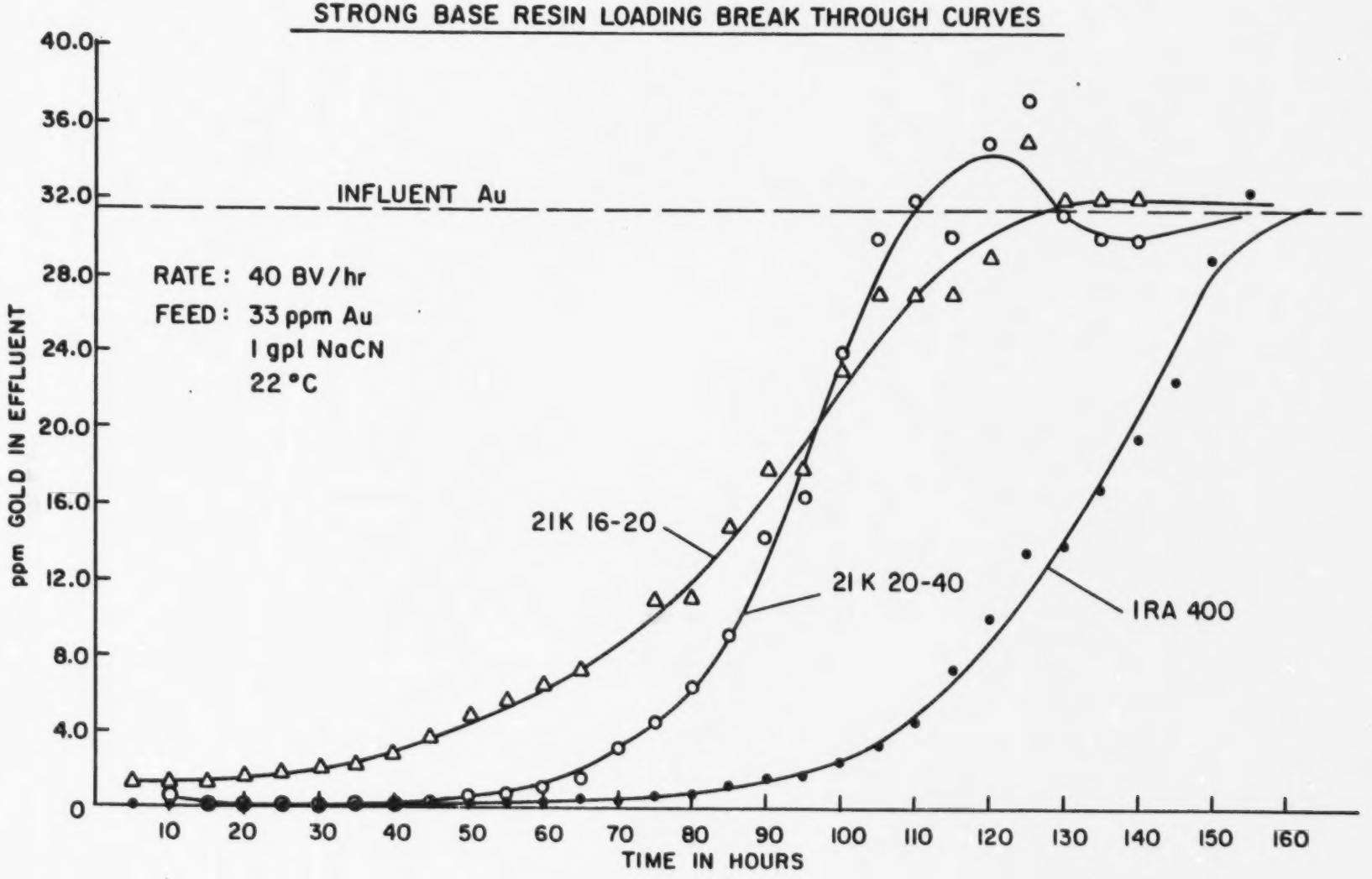

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FIGURE 13

WEAK BASE RESIN LOADING CAPACITIES

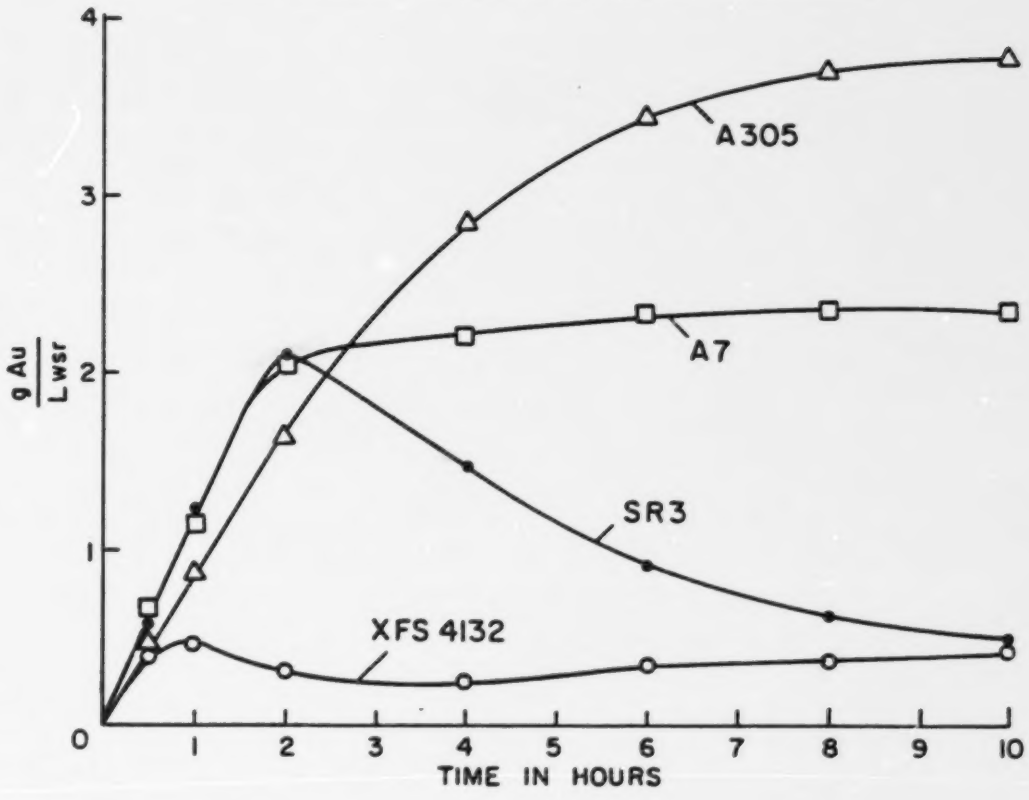

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FIGURE 14

STRONG BASE RESIN LOADING CAPACITIES

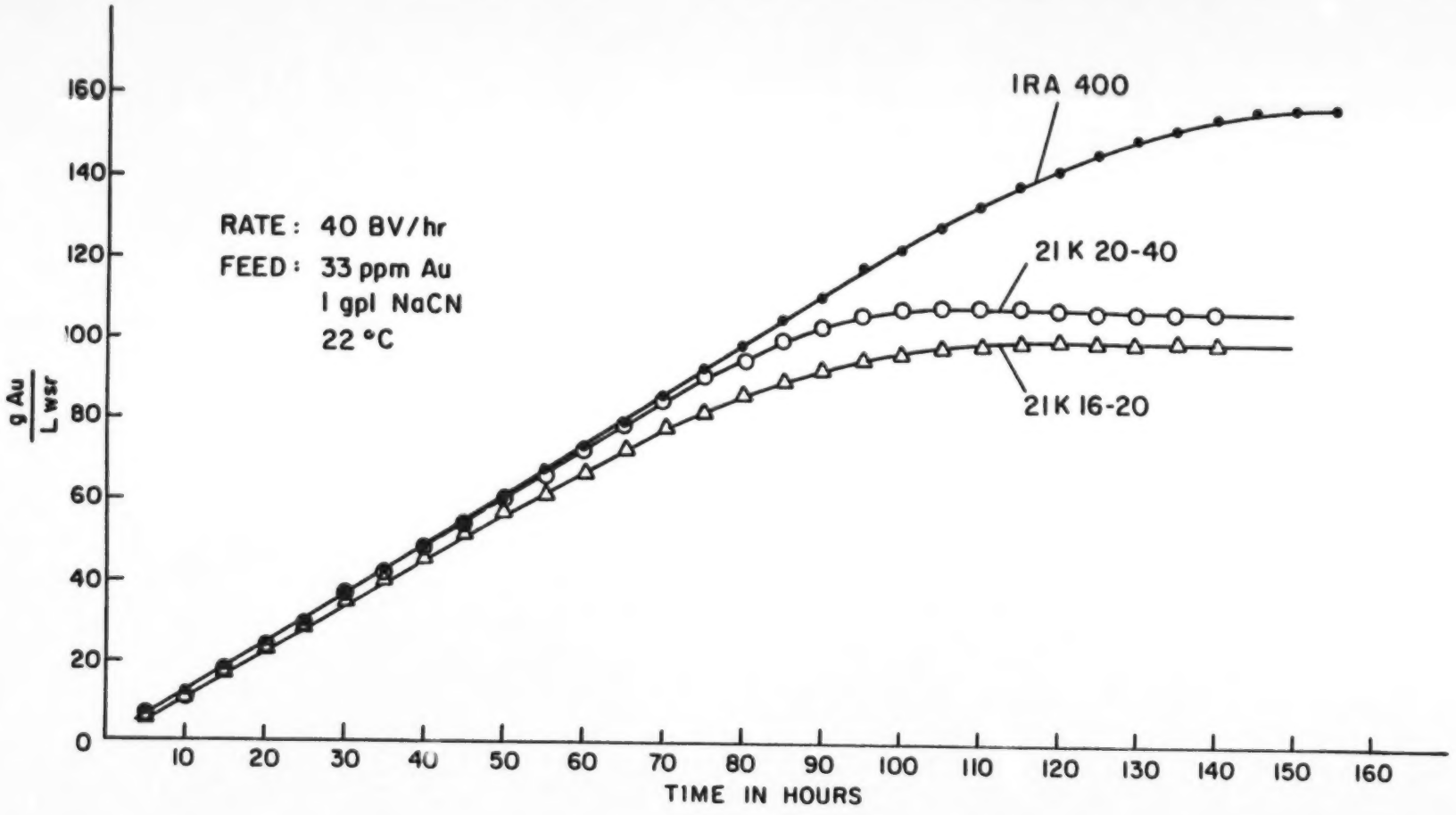

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Table 14

Strong Base Resin Stirred Tank Elution Tests

	Au Eluted (%)		
	Amberlite IRA 400	Dowex 21K 16-20M	Dowex 21K 20-40M
Low Temperature (5°C)	51.1	53.5	71.2
High Temperature (35°C)	15.5	11.7	23.9
Low ZN Concentration (5GPL ZN)	35.4	21.6	51.4
Low CN (3:1 Excess)	30.5	27.0	47.2
High CN (7:1) Excess)	33.0	33.7	56.5
Baseline	31.7	23.7	51.0

Base Conditions:
2 1/2 mls resin
100 mls solution
20 gpL Zn
5:1 Ratio CN to ZN for ZN $(CN)_4^{2-}$
25 gpL NaOH
22°C
5 minute contact
Resins loaded to approx. 45 GPL wsr

Table 15

Elution Under Varied Conditions
Weak Base Elution - % Gold Eluted

	Duolite A7	Ionac A305
Low Caustic 1 GPL	40.0	8.7
High Caustic 10 GPL	70.1	28.6
Low temp. 6°C	48.7	23.1
High Temp. (1) 35°C	75.4	24.4
High Temp. (2) 80°c	78.9	23.0
Cyanide Addition 1 GPL NaCN	52.0	29.4
Baseline	59.3	23.4

Base Condition:
2 1/2 mls resin
25 mls solution
5 gpl NaOH
22°C
5 minute contact
Resins loaded to approx. 2.5 gpl wsr

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FIGURE 15

WEAK BASE COLUMN ELUTION

% GOLD ELUTED vs. TIME/VOLUME THROUGH

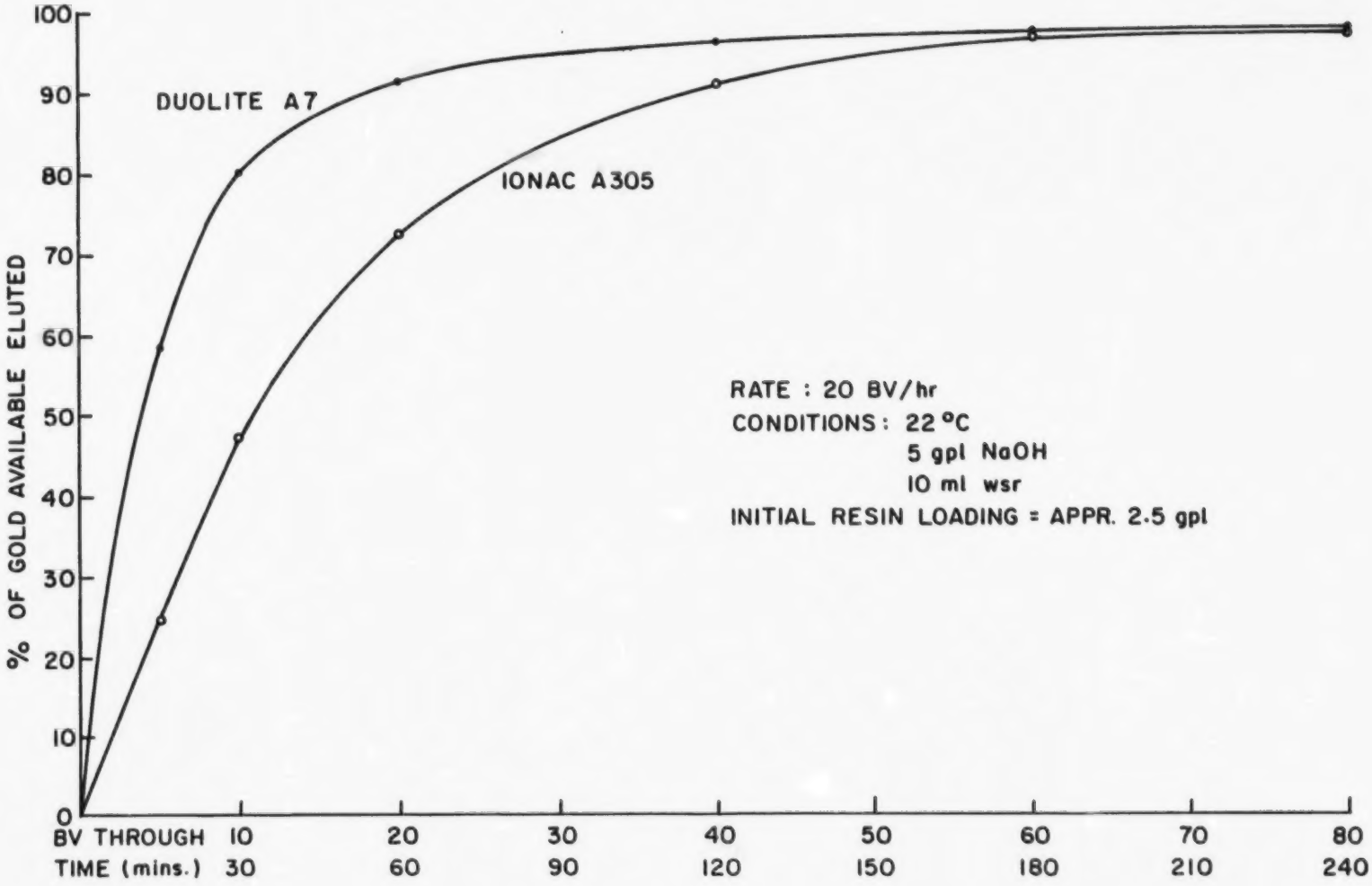

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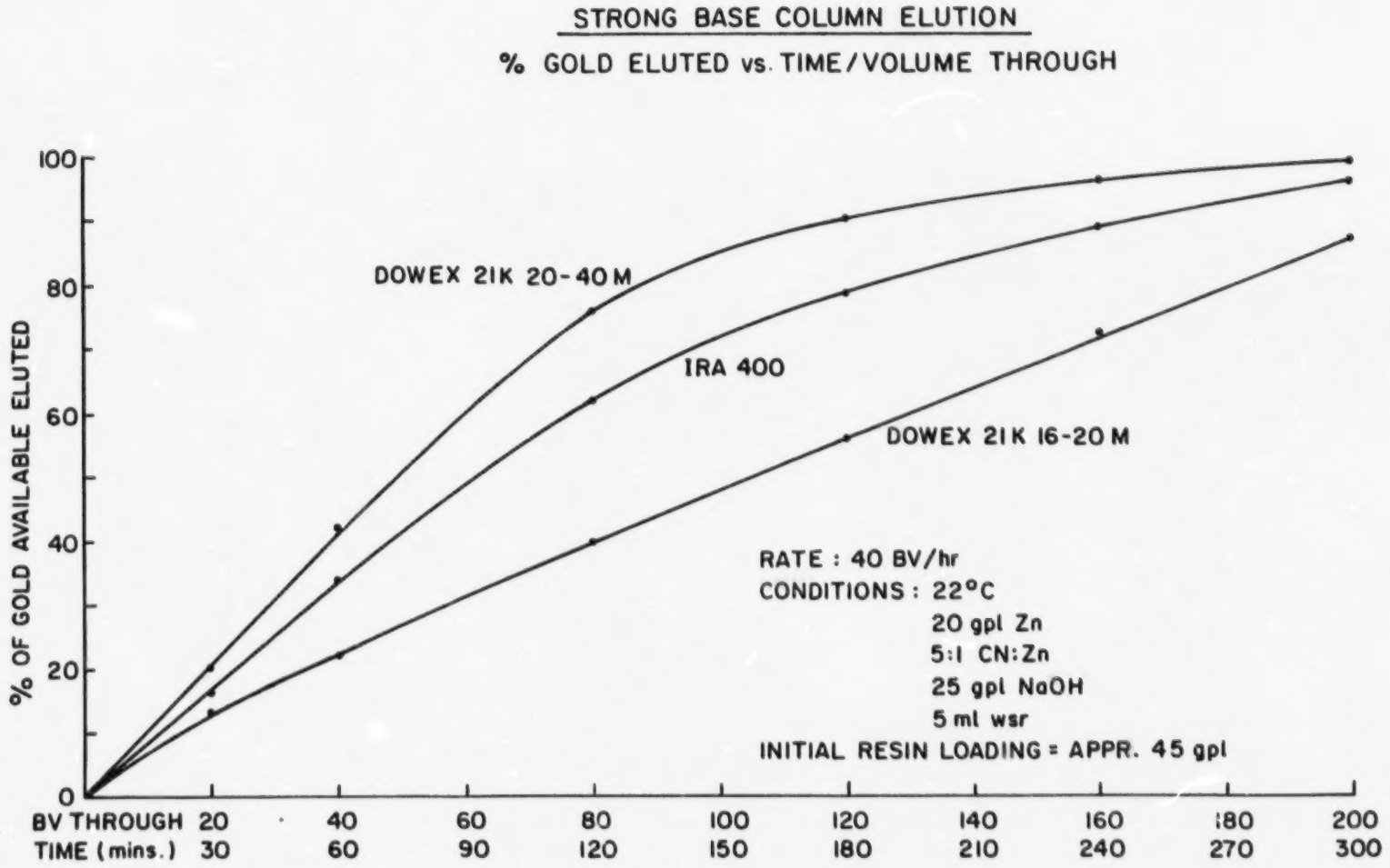
Figure 16



ORF

APPENDIX

REFERENCES

References

1. Fleming, C.A. and Nicol, M.J.; Alternative Processes to Filtration: Carbon-In-Pulp and Resin-In-Pulp in the Metallurgical Industry; Hydrometallurgy '81 Symposium (Soc. Chem. Ind. London).

2. Potter, G.M. and Salisbury, H.B.; Min. Congr. J. 1974, 60, p.54.

3. Bhappie, R.B. and Lowes, F.M.; Min. Congr. J. 1975, 61, p.38-41.

4. Carbon-In-Pulp Technology for the Extraction of Gold; Proc. Symposium, Kalgoorlie, July 1982 (Aus. I.M.M.).

5. Muir, David M.; Recovery of Gold from Cyanide Solutions using Activated Carbon: A Review; MCRU, Murdoch University.

6. Ruane, M. and Hinchliffe, W.D.; Haveluck Carbon-In-Pulp and Heap Leach Circuits - Preliminary Carbon Activity Studies; WAMPRI Research Report, Murdoch University, 1983.

7. Newrick, G.M., Woodhouse, G and Dods, D.M.G.; Carbon-In-Pulp versus Carbon-In-Leach; World Mining, vol. 36, No. 6, 1983, p.48.

8. Laxen, P.A. and Fleming, C.A.; A Review of Pilot Plant Testwork conducted on the Carbon-In-Pulp Process for the Recovery of Gold - CMMI 12th. Congress, Johannesburg, May 1982.

9. McQuiston, F.W. and Shoemaker, R.S.; Gold and Silver Cyanidation Plant Practice vol. II, Aime, 1981, p.9.

10. Jackson, D.; Pinson Gold; Engineering and Mining Journal, 1982, August, p.64-68.

11. McDougall, G.J. and Hancock, R.D.; Activated Carbons and Gold - A Literature Survey; Minerals Science and Engineering, vol. 12(2), 1980, p.85-99.

ORF

12. Davidson, R.J., Douglas, N.D. and Tumilty, J.A.; The Selection of Granular Activated Carbon for use in Carbon-In-Pulp Operation; Ref. 4, p.199.

13. Hussey, S.J., Salisbury, H.B. and Potter, G.M.; Carbon-In-Pulp Gold Adsorption from Cyanide Leach Slurries; USBM, RI 8368, 1979.

14. Fleming, C.A.; Some Aspects of the Chemistry of Carbon-In-Pulp and Resin-In-Pulp Processes; Ref. 4, p.415.

15. Laxen, P.A.; Carbon-In-Pulp Processes in South Africa; Hydrometallurgy (13), 1984, p.169-192.

16. Dahya, A.S. and King, D.J.; Developments in Carbon-In-Pulp Technology for Gold Recovery; CIM Bulletin, Sept. 1983, p.55-61.

17. Griffon, A.F. and Costello, M.C.; Carbon Desorption Process Development at Micron Research; Ref. 4, p.147.

18. Ruane, M. and Hinchcliffe, W.; Murdoch MCRO Solvent Process for the Desorption of Gold from Activated Carbon; Murdoch University Mineral Chemistry Research Unit Report, Dec. 1981.

19. Michaelis, H. Von; Innovations in Gold and Silver REcovery; Precious Metals 1982 Symposium, California, June, 1982, p.129.

20. Custom Equipment Co. Suite 172 Beneficial Life Tower, Salt Lake City, Utah.

21. Kyoritsu Yuki Co. Ltd., Tokyo, Japan, Unimech. CACT carbon Regnerator; Consolidated Chem. Co., 1 Heap Street, Chatwood, N.S.W.

22. Anon.; Gold from Russia's Murantau Deposit; Consolidated Gold Fields Report; Coal, Gold and Base Metals; vol. 26 (1978), p.75.

ORF

23. McClelland, G.E., Pool, D.L. and Eisele, J.A.; Agglomeration - Heap Leach Operations in the Precious Metals Industry; U.S.B.M., Washington, IC 8945, 1983.

24. Shoemaker, R.S. et al; Carbon-In-Pulp Processing of Gold and Silver Ores - The Experts View the Problems; Mining Engineering, September and October, 1981.

25. Heinen, H.J., Peterson, D.G. and Lindstrom, R.E.; Processing Gold Ores Using Heap Leach - Carbon Adsorption Methods; U.S.B.M., IC 8770, 1978.

26. Ross, J.R., Salisbury, H.B. and Potter, G.M.; Pressure Stripping Gold from Activated Carbon; AIME Annual Conference, Chicago, Ill., February, 1973.

27. McClelland, G.E. and Eisele, J.A.; Improvements in Heap Leaching to Recover Silver and Gold from Low-Grade Resources; U.S.B.M., RI 8612, 1982.

28. King, D.J. and Dahya, A.S.; Gold Milling - Canadian Practice; Acres Davy McKee Ltd., Toronto.

29. Envers, P.; New Concept in Mill Planning for Canadian Gold Mines; Northern Miner, Ocotober 1, 1981.

30. Becker, E., Knothe, M. and Lobel, J.; Gold Recovery from Non-Metallic Secondary Raw Materials by Leaching with Thiourea and Adsorption on Ion Exchangers; Hydrometallurgy (11), 1983, p.265-275.

31. Fridman, I.D. and Savari, E.E.; Treating Carbon Containing Ag-Au-As Concentrates; World Mining, July, 1983, p.45.

ORI

32. Law, H.H.; Recovery of Gold from Ion Exchange Resins with Dimethylformamide/Water Mixture; Precious Metals 1982, Symposium, California, June, 1982, p.503.

33. Shaw, J.A. and McDonough, R.J.; Mechanical Agitation in the Carbon-In-Pulp Process; Ref. 4, p.181.

34. Ruane, M.; Comparison of the Zadra, Anglo-American and Organic Procedures for Desorption of Gold from Activated Carbon; Ref. 4, p.393.

35. McDougall, G.J. et al; The Mechanism of the Adsorption of Gold Cyanide on Activated Carbon; Journal of the South African Institute of Mining and Metallurgy, September, 1980, p.344.

36. Nicol, D.I.; The Adsorption of Dissolved Gold on Activated Charcoal in a NIM CIX Contactor; Journal of the South African Institute of Mining and Metallurgy, December, 1979, p.497.

37. Filmer, A.O.; The Electrowinning of Gold from CIP Elucites; Ref. 4, p.49.

38. Lucas, B.H.; Separation Processes by Single-Stage Deep Fluidized Bed Continuous Ion Exchange; CIM Bulletin, March, 1980, p.195.

39. Cho, E.H., Dixon, S.N. and Pitt, C.H.; The Kinetics of Gold Cyanide Adsorption on Activated Charcoal; AIME Metallurgical Transactions, vol. 10B, June, 1979, p.185.

40. Zajtsev, V.N. et al; Absorption of Gold in Complex Cyanide Solutions; TS vetnye Metally, May, 1982, p. 103-105.

41. Young, G.J., Douglas, W.D., Hampshire, M.J.; Carbon in Pulp Process for Recovering Gold From Acid Plant Calcines at President Brand; Mining Engineering, March, 1984, p. 257.

42. Fleming, C.A. and Cromberge, G.; The Extraction of Gold From Cyanide Solutions by Strong - and Weak - Base Anion-Exchange Resins; Journal of the South African Institute of Mining and Metallurgy, May, 1984, p.125.

43. Davidson, R.J. and Strong, B.; The Extraction of Gold From Plant Effluent by the Use of Activated Carbon; Journal of the South African Institute of Mining and Metallurgy, August, 1983, p.181.

44. Nicol, M.J., Fleming, C.A. and Cromberg, G.; The Absorption of Gold Cyanide onto Activated Carbon II. Application of the Kinetic Model to Multistage Absorption Circuits; Journal of the South African Institute of Mining and Metallurgy, March, 1984, p.70.

45. Davidson, R.J.; The Mechanism of Gold Adsorption on Activated Charcoal; Journal of the South African Institute of Mining and Metallurgy, November, 1984, p.67.

46. Clarke, P.J.; Carbon and the Recovery of Gold; Metallwissenschaft und Technik, February, 1980, p.128.

47. Higgins, I.R.; Hydrometallurgical Recovery of Metal Values by the Use of Ion Exchange; Proceedings of Energy and Metallic Minerals Conference, Houston, 1981, AICLE, p.143.

48. Mason, P.G. et al; Selection of the Process Flowsheet for the Mercur Gold Plant; Precious Metals: Mining Extraction and Processing Symposium, California, 1984, p.435.

49. Potter, G.M.; Effects of Clay Content on Carbon-In-Pulp Process; World Mining, July, 1981, p.33.

ORI

50. Kyffin, D., Charles, W.D. and Wilson, D.; Gold Recovery Using Activated Carbon; Precious Metals 1983 Symposium, California, June, 1983, p.117.

51. Pizarro, R.S. and Antonio, F.V.; Mining and Processing at Masbate, Philippines; Mining Magazine, July, 1982, p.20.

52. Acton, C.F.; The Technology of Gold and Silver Extraction; AICHE Symposium Series, vol. 78, No. 216, 1982, p.127.

53. Rich, H.R., Cheong, G.E., Eupene, G.S.; The Mount Bonnie Gold Silver Project; The Aus. I.M.M. Conference, Darwin, N.T., August, 1984, p.415.

54. Nicol, M.J., Fleming, C.A., Cromberg, G.; The Absorption of Gold Cyanide onto Activated Carbon. I. The Kinetics of Absorption From Pulps; Journal of the South African Institute of Mining and Metallurgy, February, 1984, p.50.

55. Sawyer, R.J.; Process Design and Operation at Alligator Ridge Mine; Inst. of Mining and Metallurgy (Great Britain) Transactions, December, 1983, p.C187.

56. Getz, A.J. and Simpson, D.L.; Leaching of Silver and Gold Ores at Smoky Valley Mining Division, Copper Range Company; Precious Metals, 1981, Rhode Island, p.11.

57. Canning, R.G. and Woodcock, J.T.; Innovations and Problems in Gold Recovery from Ores and Mineral Products; The Aus. I.M.M. Conference, Melbourne, Vic., August, 1982, p.365.

58. Andrews, S.J. et al; Recent Developments in the Mineral Processing Industry; Mineral Processing and Extractive Metallurgy Conference, Kunming, Yunnan Province, People's Republic of China, Oct. - Nov. 1984, p.87.

59. Davison, J. et al; Ion Exchange for Gold Recovery; Transactions of the Institute of Mining and Mewtallurgy; vol. 70, No. 5; 196961; p.247.

60. Gilmore, A.J.; A Proposed Use for Ion Exchange in Gold Cyanidation; Canadian Mining Journal; vol. 88, No. 5; May, 1967; p.63.

61. Gilmore, A.J.; A Proposed Method for Gold Recovery From Flotation Plant Effluents with Activated Carbon;

ORF